Ministry of National
Development Planning/Bappenas
Republic of Indonesia

Decarbonization
ROADMAP OF INDONESIA'S NICKEL INDUSTRY

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Contribution Appreciation

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- Ministry of National Development Planning (PPN) /Bappenas
- Coordinating Ministry for Economic Affairs
- Ministry of Energy and Mineral Resources
- Financial Services Authority (OJK)
- National Research and Innovation Agency (BRIN)
- Ministry of Industry
- Ministry of Finance
- Ministry of Investment /Investment Coordinating Board (BKPM)
- National Standards Agency (BSN)
- PT Sarana Multi Infrastruktur (SMI)
- Coordinating Ministry for Maritime Affairs and Investment

Industry, Industrial Estates, and Industry Associations

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- PT Pertamina Persero
- PT Vale Indonesia Tbk
- Harita Nickel Group
- PT ANTAM Tbk
- PT Weda Bay Nickel
- PT Wanatiara Persada
- Nickel Industries Ltd.
- PT Obisidian Stainless Steel
- PT Virtue Dragon Nickel Industry
- PT Gunbuster Nickel Industri
- PT Merdeka Battery Materials Tbk
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- PT Huafei Nickel Cobalt
- PT Huayue Nickel Cobalt
- Tsingshan Group
- PT Wanxiang Nickel Indonesia
- Indonesia Morowali Industrial Park
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Foreword

By offering praise to the presence of God Almighty, we are proud to present **Indonesia’s Nickel Decarbonization Roadmap**. This document is an integral part of our strategic efforts to support the transition to a green economy and sustainable development. The preparation of this roadmap is the result of collaboration between the Ministry of National Development Planning/Bappenas and the World Resources Institute (WRI) Indonesia.

This roadmap aims to serve as a comprehensive guideline for all stakeholders in the nickel industry. The goal is to achieve decarbonization targets that are in line with national commitments to reduce greenhouse gas emissions as well as achieving Net Zero Emissions by 2060 or sooner.

As one of the largest nickel-producing countries in the world, Indonesia has an important role in the global supply chain, particularly in supporting the electric vehicle and renewable energy industries. However, the nickel industry also faces major challenges related to the environmental impact caused by its extraction and processing process. Therefore, this roadmap aims to provide a clear direction in reducing the carbon footprint of the nickel sector through various innovative strategies, including strengthening regulations and standards for green industries, using renewable energy as an energy source, improving production process efficiency, implementing low-carbon technologies, preparing funding mechanisms for decarbonization, strengthening the green industry market, and improving sustainability standards.

The preparation of this roadmap involved a wide range of stakeholders, including governments, industry players, and civil society organizations, to ensure that the measures taken can be implemented effectively and provide long-term benefits. Through policy synergy, green funding and low-carbon technology innovation, Indonesia’s nickel industry is expected to develop competitively and environmentally friendly so that it can contribute to the achievement of the Net Zero Emission target.

We hope that this document can be a comprehensive guide that can be implemented by all parties in realizing a more environmentally friendly and globally competitive nickel industry. We would like to thank all parties who have contributed to the preparation of this roadmap. Hopefully, this document will be the first step in a collective effort to encourage the decarbonization of the nickel industry in Indonesia, provide benefits for environmental sustainability, and improve people’s welfare.

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Executive Summary

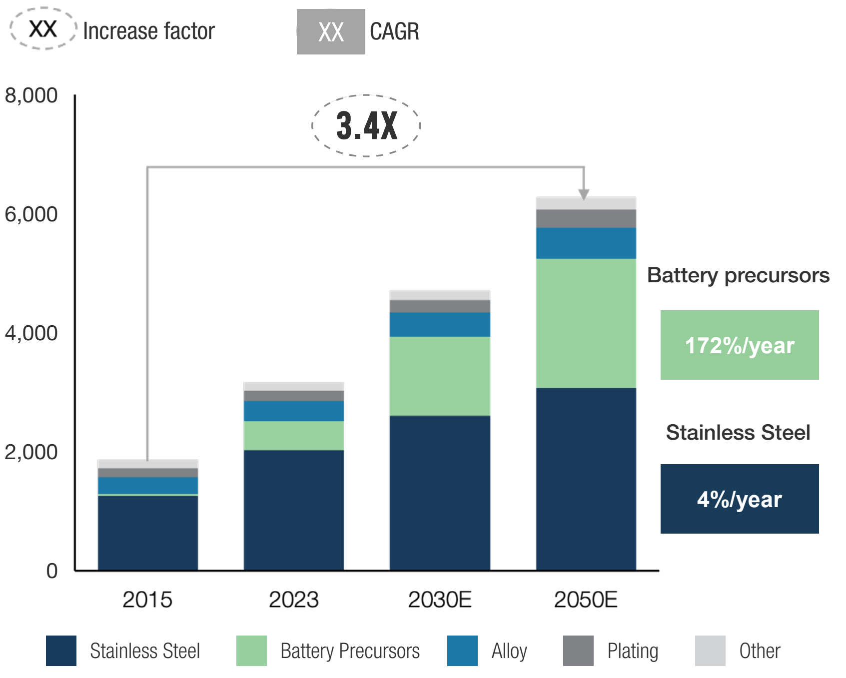
As the world's 60% producer of nickel, Indonesia is strategically positioned to become a green powerhouse – a supplier of green minerals needed in the global energy transition. The National Nickel Industry Decarbonization Roadmap has been developed as a guide for the government, industry, and society to realize a low-carbon nickel industry, in line with the Golden Indonesia 2045 Vision outlined in the 2025–2060 National Long-Term Development Plan (RPJPN). For the industry, this document provides a trajectory that serves as a reference in setting emission reduction targets at the company level, in response to growing demand for low-carbon products from downstream industries, financial institutions, and consumers. Meanwhile, for the government, the roadmap offers policy recommendations to build an ecosystem that supports the implementation of decarbonization strategies, considering persistent challenges such as limited infrastructure, high costs, and regulatory uncertainty.

Decarbonization is becoming inevitable as demand for nickel in low-carbon technologies increases

Nickel is a material used by various industries and is commonly used as a raw material for stainless steel and alloy materials. In recent years, the demand for nickel has increased due to its role in low carbon technology (LCT) to support global net zero emission targets. Nickel is a key material in LCTs used in electric vehicle batteries, renewable energy generation components such as Wind Power Plants (WPP), piping in Geothermal Power Plants (GPP), as well as electrolysers for hydrogen production.

Although nickel-based electric vehicle batteries (NMC & NCA) compete with lithium (Lithium Iron Phosphate/LFP) batteries that do not use nickel, nickel demand for batteries is projected to continue to grow significantly at an average of 172% per year through 2050 (see **Figure I**). In contrast, the growth of nickel as a material for stainless steel is expected to be slower, at around 4% annually, and will be highly influenced by the economic conditions of China, the main producer and exporter.

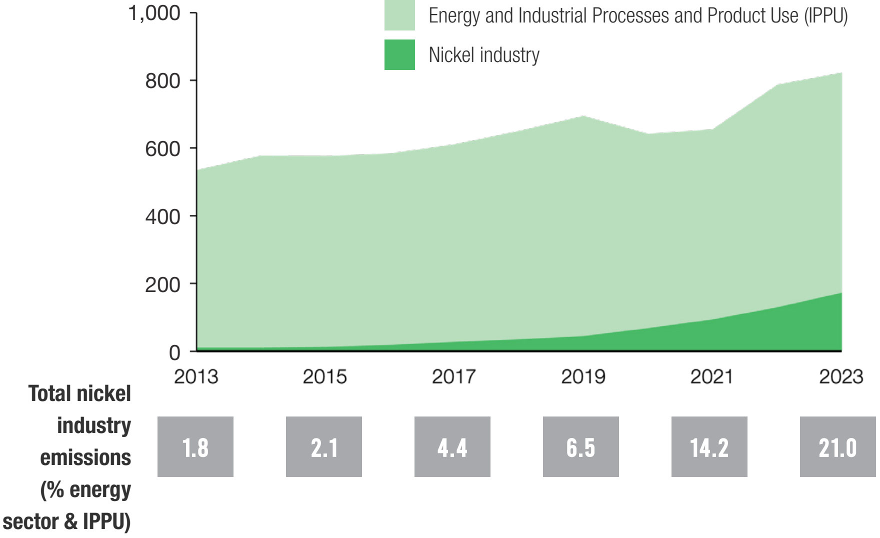
Figure I.
Global nickel demand projections by end product
Kt Ni-eq



According to data from the United States Geological Survey (USGS) in 2024, Indonesia holds the world's largest nickel reserves (55 million tons of nickel, or 42.3% of global total) and dominates nickel ore mining, accounting for up to 60% of global supply. In addition, Indonesia contributes 39.8% of the global production of semi-finished nickel products such as ferronickel, nickel pig iron (NPI), mixed hydroxide precipitate (MHP), matte, and others. With nickel demand expected to double by 2050, Indonesia has a significant opportunity to strengthen its role in the battery and stainless steel industries. Its position as the world's largest producer of both nickel ore and semi-finished nickel products supports a strategic move toward downstream supply chains, aligned with the National Long-Term Development Plan (RPJPN) 2025–2045 and the government's downstream industrialization strategy.

Figure II.
Climate impact of nickel industry

GHG Emissions, Million Tons CO_2e



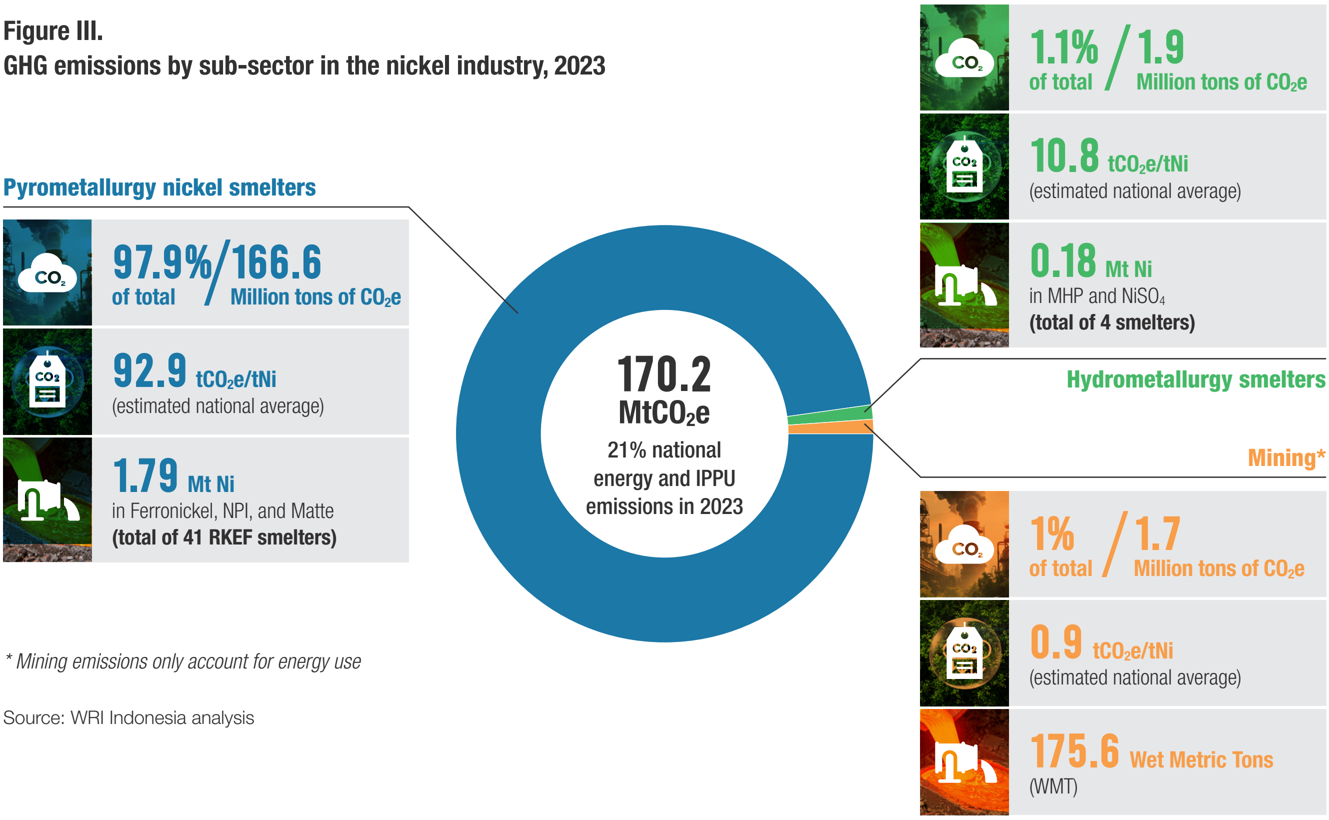
However, the growth of Indonesia's nickel industry has also led to a surge in greenhouse gas (GHG) emissions of up to 170.2 million tonnes of CO_2e in 2023 or equivalent to 21% of the national energy and Industrial Process and Product Use (IPPU) emissions in the same year – a sharp jump from just 9.8 million tonnes of CO_2e in 2013 (see **Figure II**). The results of this study show that 64% of the increase of 160.4 million tons of CO_2e from 2013 to 2023 is due to emissions that have occurred since 2020. This increase was triggered by the expansion of industry and the dominance of RKEF technology as a process of smelting nickel (pyrometallurgy) into semi-finished products such as NPI, ferronickel, and nickel matte.

If not anticipated, emissions from nickel downstream risk hindering the achievement of Indonesia's climate targets as stated in the Nationally Determined Contribution (NDC), RPJPN Law, and the Long-Term Strategy for Low-Carbon and Climate Resilience (LTS-LCCR) document. In the Enhanced NDC (ENDC) document, Indonesia targets a reduction in GHG emissions by 2030 of at least 31.9% with its own capabilities and 43.2% with international assistance. For the long term, Indonesia has also targeted an emission reduction of 80.98% by 2045 as stipulated in the RPJPN Law. The target is also in line with the target in the LTS-LCCR document to achieve Net Zero Emissions (NZE) by 2060.

What is the largest source of carbon emissions in the nickel industry?

The RKEF technology, which is highly energy-intensive and dependent on coal, contributed around 166.6 million tons of CO_2e, or 98% of total emissions from the nickel industry in 2023 (see **Figure III**). Compared to other technologies such as flash smelting or hydrometallurgical methods like High Pressure Acid Leaching (HPAL) and bioleaching, the RKEF process generates greenhouse gas (GHG) emissions 7 to 10 times higher per ton of pure nickel metal produced. One reason hydrometallurgy technologies produce lower emissions is the adoption of waste heat recovery systems in HPAL facilities, which reduces coal combustion. Meanwhile, in the mining segment, emissions—mainly from the use of heavy equipment and vehicles—only contribute 1.7 million tons of CO_2e, or 1% of total emissions.

Figure III.
GHG emissions by sub-sector in the nickel industry, 2023

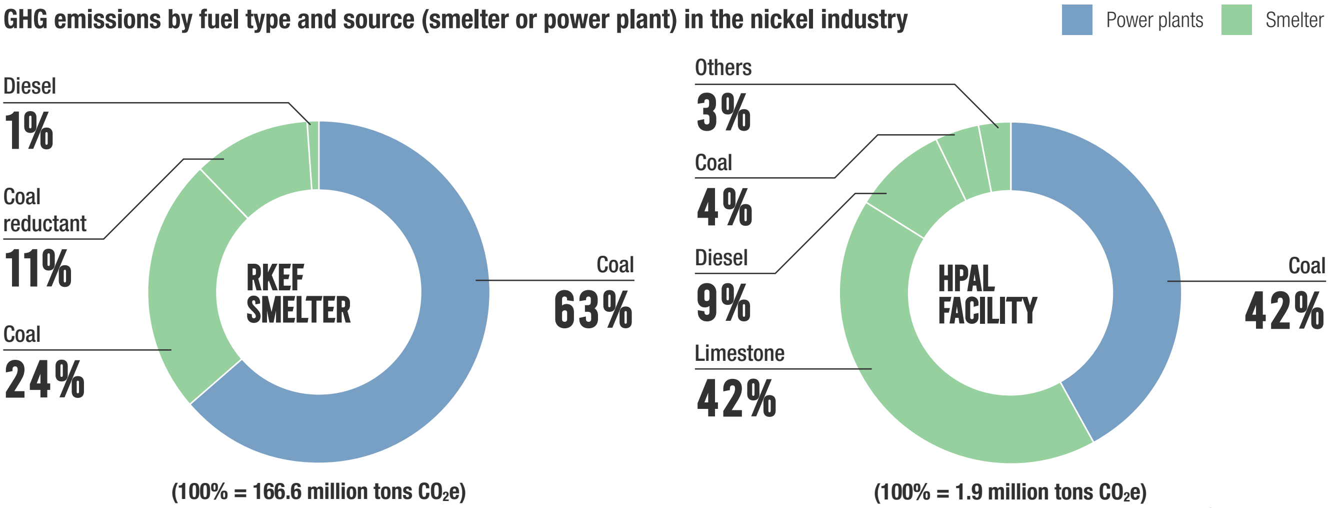


** Mining emissions only account for energy use*

Source: WRI Indonesia analysis

The main source of carbon emissions in nickel smelter facilities comes from power plants, due to the intensive electricity required for nickel processing and the coal-dominated energy mix. Around 97% of the electricity supply comes from coal-fired power plants (CFPP), which produce large amounts of emissions. Power plants integrated with RKEF smelters are estimated to emit 106.2 million tons of CO_2e annually, while power plants supplying HPAL facilities contribute around 0.8 million tons of CO_2e. Combined, emissions from power generation in the nickel industry reach 107.0 million tons of CO_2e, equivalent to 26% of total emissions from the national power generation sector. Proportionally, power generation accounts for 63.5% of total emissions at RKEF smelters, and 42.3% at HPAL facilities, while the remaining emissions come from the smelters, mainly fuel combustion and material use in the production process.

Figure IV.
GHG emissions by fuel type and source (smelter or power plant) in the nickel industry



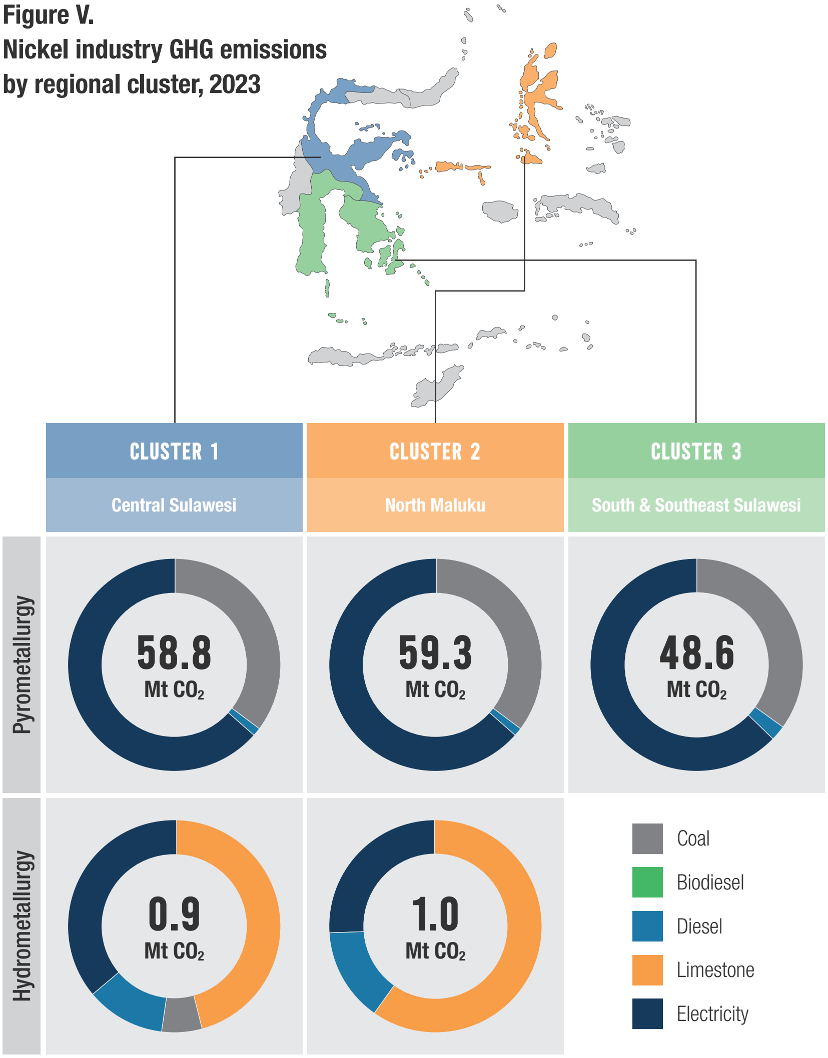
Source: Author

The Roadmap is focused on three clusters of the main nickel-producing regions

The majority of nickel production facilities, such as mines and smelters, are located in three regional clusters: Central Sulawesi (Cluster 1), North Maluku (Cluster 2), and Southeast and South Sulawesi (Cluster 3). These three clusters are the main focus of the decarbonization roadmap for the nickel mining and primary extraction sub-sector. In 2023, which serves as the base year used in this roadmap, there were 300 active Mining Business Licenses (IUP) and 51 processing or smelter facilities.

Cluster 1 and Cluster 2 were the regions with the highest emissions in 2023 due to the large production capacity of nickel smelters in both clusters. Meanwhile, Cluster 3 recorded relatively lower emissions because of the smaller number of smelters and the presence of smelters powered by hydroelectric power plants (HPP). In general, the composition of emission sources is dominated by the direct use of coal in smelting processes and as fuel in CFPP.

Figure V.
Nickel industry GHG emissions by regional cluster, 2023



Four strategies for decarbonizing the nickel industry

Based on our study, decarbonization efforts in the nickel industry by 20 mining and processing companies interviewed have been largely dominated by measures with relatively low emission reduction impact, such as the use of biodiesel for vehicles and tree planting. It is important to note that tree planting does not reduce emissions in absolute terms but instead removes carbon from the atmosphere (removal). Meanwhile, initiatives with greater emission reduction potential, such as the use of renewable energy, electrification of heavy equipment, and the substitution of coal with biomass or hydrogen, are still limited in implementation or are still in the planning and/or trial stages.

Therefore, to address the challenge of realizing more significant decarbonization, this roadmap concentrates on absolute emission reductions with four (4) main approaches:

- **Energy efficiency**, with a focus on optimizing mass and energy balances to avoid emissions-producing activities.
- **The switch of high-emission fuels to low-carbon alternatives,** taking into account the technical and combustion characteristics of each fuel.
- **Material substitution**, which is the replacement of raw materials or chemical reagents in the production

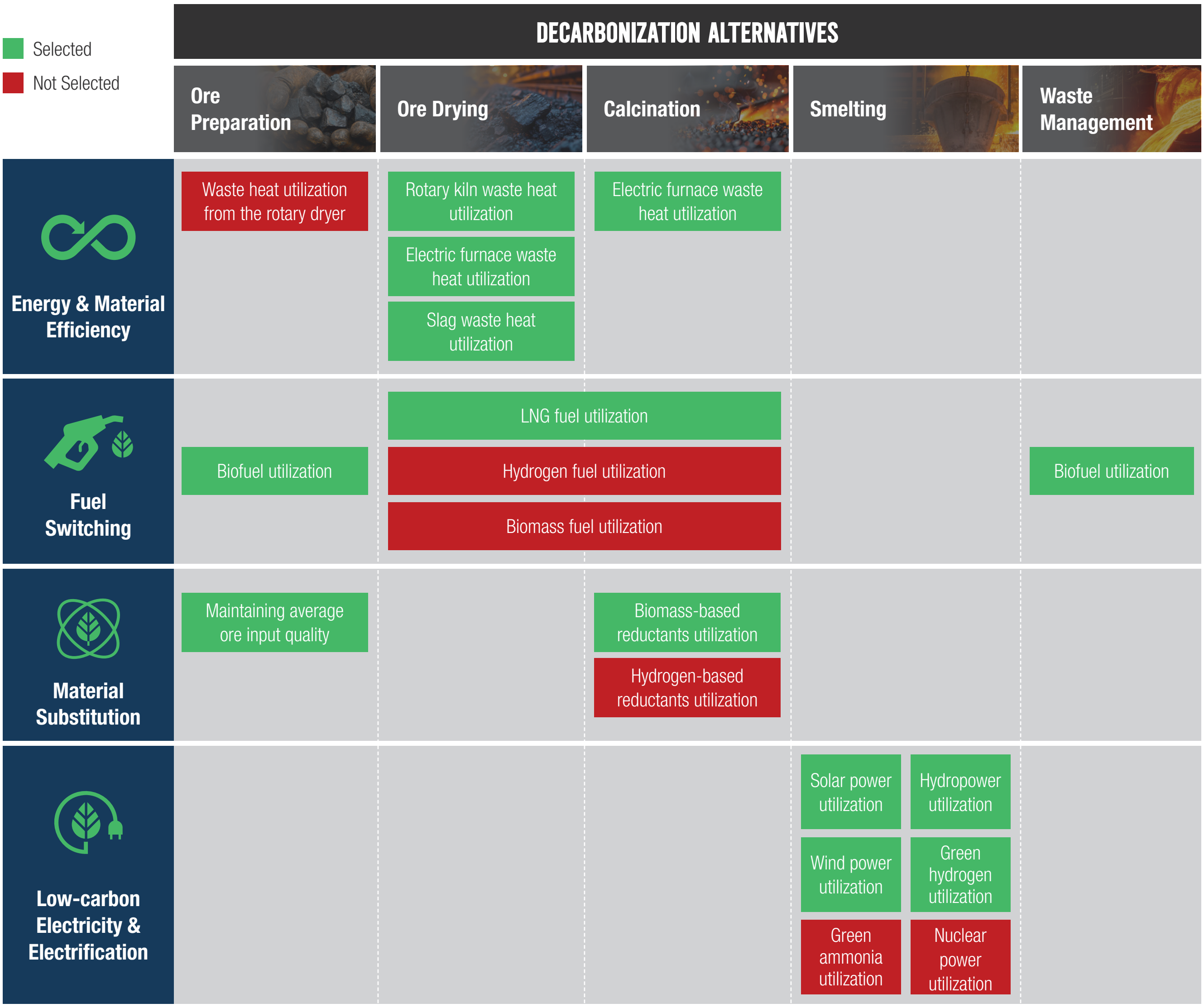
  process to produce less greenhouse gas emissions.
- **Low-carbon electricity & electrification**, by encouraging the use of low-carbon power plants and assessing potential energy substitution based on capacity and technical efficiency.

This roadmap emphasizes absolute emission reduction (abatement) and does not include removal efforts that will be considered after the potential abatement is maximized. For each of the above-mentioned approaches, decarbonization alternatives were selected based on four main criteria:

- Potential emission reduction
- Technology Readiness Level (TRL)
- Risk to production process
- CAPEX & OPEX

The selected decarbonization alternatives in this roadmap are presented in **Figure V**. Only technologies that are proven and have begun to be implemented in the field are included in the scenario (with a minimum Technology Readiness Level of 8), except in special cases such as the use of hydrogen in Cluster 2, which is considered due to the limited availability of conventional renewable energy sources. Implementation risks and non-emission environmental impacts are also important considerations in this selection.

Gambar VI.
Alternatives to decarbonization actions selected in the roadmap



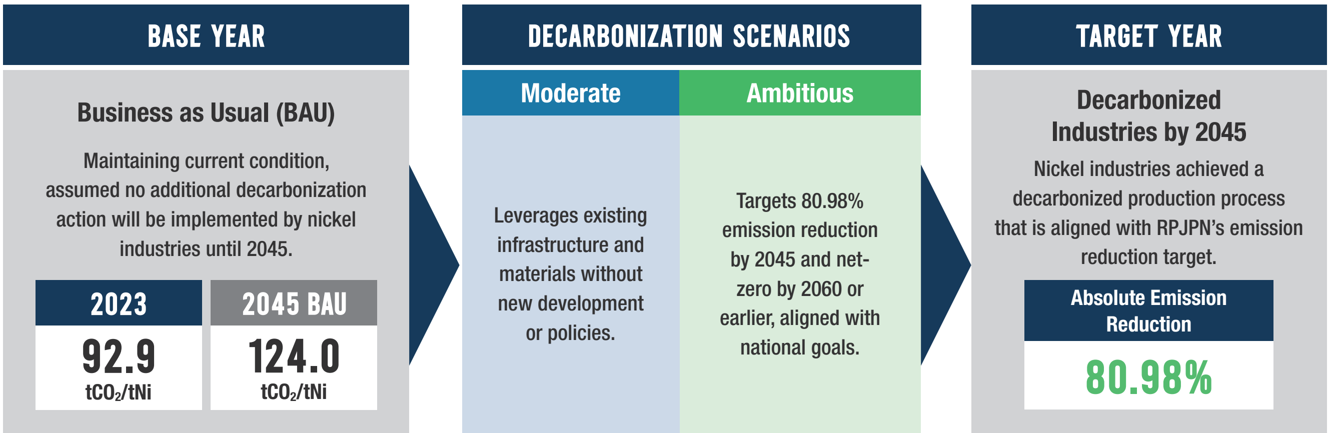
🟩 Selected
🟥 Not Selected

	DECARBONIZATION ALTERNATIVES				
	Ore Preparation	Ore Drying	Calcination	Smelting	Waste Management
Energy & Material Efficiency	🟥 Waste heat utilization from the rotary dryer	🟩 Rotary kiln waste heat utilization 🟩 Electric furnace waste heat utilization 🟩 Slag waste heat utilization	🟩 Electric furnace waste heat utilization		
Fuel Switching	🟩 Biofuel utilization	🟩 LNG fuel utilization 🟥 Hydrogen fuel utilization 🟥 Biomass fuel utilization			🟩 Biofuel utilization
Material Substitution	🟩 Maintaining average ore input quality		🟩 Biomass-based reductants utilization 🟥 Hydrogen-based reductants utilization		
Low-carbon Electricity & Electrification				🟩 Solar power utilization 🟩 Hydropower utilization 🟩 Wind power utilization 🟩 Green hydrogen utilization 🟥 Green ammonia utilization 🟥 Nuclear power utilization	

The decarbonization pathway of the nickel industry is in line with the national emission reduction target in the 2025-2045 RPJPN

This roadmap considers three (3) scenarios for decarbonization actions, namely: (1) Business As Usual (BaU) Scenario which assumes no decarbonization actions other than those that have been carried out in 2023 and before, (2) Moderate Scenario, which assumes that decarbonization will advance, but only by maximizing the use of existing infrastructure (e.g., grid, LNG terminals) and available materials, with no further infrastructure development or new decarbonization policies introduced, and (3) The Ambitious Scenario outlines the pathway required for the nickel industry to meet Indonesia's national emission reduction target of 80.98 percent by 2045, as set out in the RPJPN. Under this scenario, the industry is placed on a trajectory toward achieving net-zero emissions (NZE) by 2060 or earlier.

Figure VII.
Nickel industry decarbonization scenario in the roadmap



BASE YEAR

Business as Usual (BAU)

Maintaining current condition, assumed no additional decarbonization action will be implemented by nickel industries until 2045.

2023	2045 BAU
92.9 tCO_2/tNi	124.0 tCO_2/tNi

DECARBONIZATION SCENARIOS

Moderate	Ambitious
Leverages existing infrastructure and materials without new development or policies.	Targets 80.98% emission reduction by 2045 and net-zero by 2060 or earlier, aligned with national goals.

TARGET YEAR

Decarbonized Industries by 2045

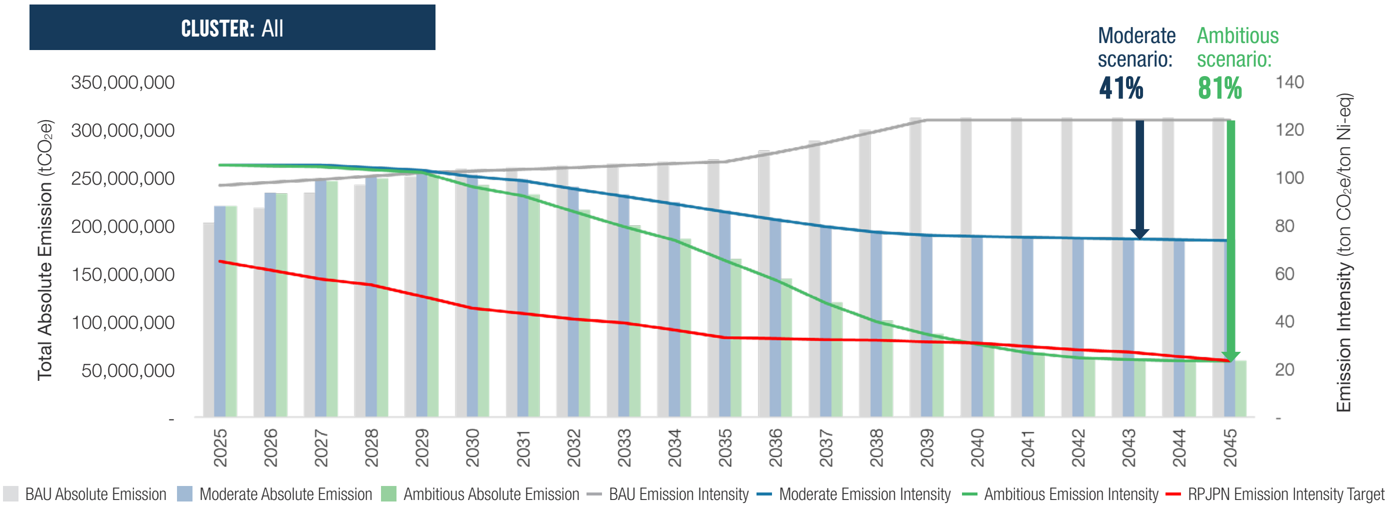
Nickel industries achieved a decarbonized production process that is aligned with RPJPN's emission reduction target.

Absolute Emission Reduction

80.98%

A comparison between the three scenarios below shows that the BaU Scenario results in a significant increase in emissions due to the growth in production capacity and declining nickel ore grades. The Moderate Scenario, while capable of gradually reducing emission intensity, is still unable to curb absolute emissions in Clusters 1 and 2. Only the Ambitious Scenario consistently meets the emission reduction targets set in the RPJPN 2025–2045, with a potential reduction of 253.3 million tons of CO_2e (81% of BaU levels) by 2045, surpassing the national target. Therefore, the Ambitious Scenario has been selected as the foundation for implementing the nickel industry's decarbonization roadmap moving forward.

Figure VIII.
Projected absolute emissions and emission intensity under different scenarios



Action plan for realizing a low-carbon and highly competitive nickel industry

The implementation of the roadmap with Ambitious Scenarios is carried out in stages over four phases of time, starting from:

Setting Up Transition Foundation (2025-2029)

Basic Infrastructure Development and Early Phase Strategy Adoption (2030-2034)

Adoption of Advanced Phase Strategy and Development Towards a Mature Market (2035-2039)

Adoption of Optimal Phase Strategy and Achievement of Emission Reduction Targets (2040-2045)

To achieve this goal, there are eight key policy directions for transforming the low-carbon nickel industry supply chain from 2025 to 2045 (see **Figure VI**):

1 Transitioning the power system of the nickel industry

To realize the energy transition within the nickel industry's power system, this roadmap recommends providing on-grid electricity for Clusters 1 and 3 located in Sulawesi, given the abundant access to renewable energy in these regions. Meanwhile, the model for Cluster 2 (North Maluku) is off-grid. The on-grid model requires expansion of PLN's transmission and distribution networks connected to industrial zones, whereas the off-grid model relies on smaller-scale, self-sufficient power systems developed by private actors. However, this policy direction is not yet fully aligned with the National Electricity General Plan (RUKN) 2025–2060 and the Electricity Supply Business Plan (RUPTL) 2025–2034, and therefore, updates to both RUKN and RUPTL are needed to increase the integration of renewable energy and expand transmission infrastructure.

This transition must also be supported by a more attractive investment climate, including adjustments to the benchmark electricity purchase price to ensure a minimum profit margin of 5% for PLN and Independent Power Producers (IPPs), while also allowing the nickel industry to maintain at least a 10% margin. Legal certainty is another crucial aspect, which can be achieved through: (1) guidelines to enhance clarity of environmental impact assessment (EIA) for power projects, (2) designation of special zones for clean energy projects in the Spatial Plan (e.g., RTRW), and (3) land price regulation to prevent speculative practices and extortion.

In addition, financing challenges must be addressed to realize this transition. High interest rates and short power purchase agreement (PPA) durations make renewable energy projects appear high-risk. Therefore, extending contract periods, providing government guarantees, and offering incentives to banks to make green financing more competitive can be effective solutions. On the other hand, there is a need to optimize the implementation of Public-Private Partnerships (PPP) and innovative financing mechanisms that can support both commercial and non-commercial power projects, such as electric grid construction and early retirement of coal-fired power plants (CFPP).

2 Development of an integrated green hydrogen supply chain for clean power generation

A green hydrogen supply chain is a critical element for decarbonising Cluster 2, which faces limited renewable energy potential. This roadmap recommends sourcing green hydrogen from Sulawesi, East Nusa Tenggara (NTT), and Papua, to be transported to North Maluku in liquid form using low-carbon vessels. The hydrogen would then be regasified centrally and used in Combined Cycle Gas Turbine (PLTGU) power plants to generate clean electricity, which would be distributed to industrial facilities. Without subsidies, the cost of hydrogen would result in negative profit margins for the nickel industry. To ensure competitiveness, a total subsidy of USD 50.2 billion is needed through 2045. This funding could be sourced by reallocating 75% of nickel royalty revenues, in accordance with Government Regulation No. 19/2025. The development of green hydrogen supply chain infrastructure must also be supported by Public-Private Partnership (PPP) schemes. Meanwhile, private investment in downstream facilities (such as captive PLTGU plants) requires fiscal incentives, including import duty exemptions for key technologies. To ensure that the roadmap supports a genuinely low-carbon transition, it is also necessary to establish a national emissions standard for green hydrogen—in order to avoid lifecycle emissions trade-offs and ensure accountability across the supply chain.

3 Development of sustainable biomass supply chains for bioreductant production

In the nickel industry, calcine reduction—the stage in which nickel and iron metals are reduced from dried ore using anthracite coal—accounts for approximately 26% of total nickel industry emissions. Decarbonising this process depends on substituting coal with biomass-based bioreductants, amounting to 9.6 million tons per year. This effort requires a reliable biomass supply chain, encompassing raw material availability, supply stability, and pre-treatment facilities to process raw biomass into biochar through pyrolysis.

Limited domestic biomass production, the dominance of exports to foreign markets, and the absence of national standards are the main challenges to developing biomass for bioreductant production. Therefore, this roadmap recommends the establishment of a biochar/bioreductant production industry as the key driver of the supply chain, the setting of a biomass reference price at USD 140 per ton to attract supply to the domestic market, and the acceleration of technical regulations, including the issuance of an Indonesian National Standard (SNI) for quality standardization and the implementation of environmental safeguards to prevent the risk of deforestation.

From a financing perspective, the development of the biomass supply chain needs to be supported through private investment, including the use of commercial loans. In addition, palm oil export levy funds, which have so far been primarily allocated to biodiesel, also have the potential to be redirected toward biochar/bioreductant development. This possibility requires further study to determine the appropriate allocation amount and ensure its effectiveness.

4 Expansion of natural gas supply for non-electric coal substitution

The substitution of coal with natural gas or LNG in rotary dryers and rotary kilns used in RKEF processes can be met through existing natural gas reserves. For Clusters 1 and 3, supply may come from existing gas fields in Central Sulawesi and new potential in the Tedong well. Meanwhile, Cluster 2 can be supplied by the Masela gas field. However, based on the National Master Plan for Natural Gas Transmission and Distribution Networks 2024–2033, as outlined in Ministerial Decree of Energy and Mineral Resources (ESDM) No. 173.K/MG.01/MEM/M/2024, there are currently no planned transmission and distribution networks for LNG in Sulawesi and Maluku. This gap requires additional investment in storage tanks and regasification facilities. Therefore, a study is needed to define infrastructure responsibilities between the government, industrial zones, and individual smelters to identify the lowest-cost option. The infrastructure planning process should be supported by a legal basis through a revision of Ministerial Decree ESDM No. 173 of 2024.

From a pricing standpoint, LNG is currently more expensive than coal. To maintain a minimum industry margin of 10 percent, it is necessary to set a specific natural gas price (HGBT) for the nickel industry at a maximum of USD 6.161 per terajoule, or approximately USD 6.5 per MMBtu. This pricing can be supported by allocating supply from new LNG fields under a scheme that reduces non-tax state revenues (PNBP) to lower project risk. The setting of HGBT must also be accompanied by improved distribution governance to ensure that supply is actually delivered to the intended beneficiaries. LNG infrastructure financing is recommended through a blended financing scheme with risk assurance support from institutions such as PT PII. Meanwhile, the construction of regasification facilities can use the shared regasification facilities model or industrial cluster approach to improve the efficiency of the construction of regasification facilities financed by each nickel industry.

5 Improved energy efficiency performance of nickel smelters

Commercially available technologies for recovering residual heat from rotary kilns, electric furnaces, and slag are already in place. The main challenge in implementing this policy lies in the layout limitations of older smelters, where the facilities are spread out and thus prevent optimal utilization of waste heat. In contrast, smelters constructed in recent years have been designed with layouts that allow for the optimization of waste heat recovery. As a result, this roadmap targets the implementation of this technology in 80 percent of existing smelters and mandates its application in all new smelters built after 2030. Nickel industries that consume more than 0.042 TJ/year of energy are required to carry out energy conservation measures, in accordance with Government Regulation No. 33 of 2023 and Minister of Energy and Mineral Resources Regulation No. 8 of 2025. The enforcement of this policy can be strengthened by setting specific energy efficiency targets for smelter companies operating RKEF facilities. These targets can serve as a benchmark for environmental feasibility standards and compliance levels, to be integrated into the Environmental Impact Assessment (EIA) and Environmental Management and Monitoring Plan (RKL-RPL).

To accelerate adoption, technology transfer is needed through concrete collaboration among research institutions, industry players, and technology providers. The SINERGI platform, managed by the Minister of Energy and Mineral Resources, can be utilized for the integration of reporting, planning, and financing related to energy conservation. In addition, the Financial Services Authority (OJK) is expected to include energy efficiency—particularly waste heat utilization—within the national green taxonomy, thereby making such activities eligible for green financing. The SINERGI platform can also serve as a space for financing institutions to list their programs or financial products related to energy efficiency, enabling the private sector to effectively access green financing schemes.

6 Increasing the biodiesel blend target in Indonesia

The use of all vehicles operated within the nickel industry contributes 0.78 percent of total emissions. The decarbonization strategy involves gradually increasing the biodiesel blend, which requires ensuring availability, sustainability, and price affordability. The nickel industry's biodiesel demand in 2025 represents only 3 percent of total national production capacity. However, the absence of medium- and long-term targets beyond 2025 creates uncertainty regarding future demand fulfilment. This roadmap recommends increasing the biodiesel blend to 50 percent (B50) by 2035, 60 percent (B60) by 2040, and 70 percent (B70) by 2045. Based on these projections, approximately 770.7 million litres of biodiesel will be needed by the nickel industry in 2045 to meet its decarbonization goals. To ensure this supply, it is necessary to establish a minimum blending roadmap, accelerate research and pilot projects, and implement off-take agreements between the nickel industry and energy producers. Additionally, reallocating biodiesel export quotas to the domestic market could help address potential future supply shortfalls.

The biodiesel supply chain must also ensure that raw materials come from sources that do not contribute to deforestation, mirroring similar concerns raised regarding bioreductant feedstocks. On the pricing side, increased biodiesel blending has pushed the price of B40 to around IDR 14,500–15,000 per litre, which poses a cost burden on non-PSO industries such as nickel. Through the Market Price Index (MIP), the government must continue to ensure that price increases remain under control to maintain the economic viability of this transition.

7 Improving national nickel decarbonization governance

To ensure the effectiveness of decarbonization strategies in the nickel industry, a robust governance system is needed. This includes a regulatory framework and infrastructure such as reporting platforms and institutional arrangements, along with a set of supporting instruments including emission calculation methodologies, performance standards, and incentive and disincentive mechanisms. Currently, GHG emission policies are managed in a fragmented manner by three ministries—energy sector emissions fall under the Minister of Energy and Mineral Resources, IPPU emissions under the Ministry of Industry, and waste-related emissions under the Ministry of Environment (KLH)—with data reporting that is often redundant and incomplete. Therefore, a cross-sectoral emissions and decarbonization governance system is required.

In the context of the nickel industry, the SIINas platform, overseen by the Ministry of Industry, will serve as the primary channel for reporting all GHG emission data, including emission activity data and the outcomes of mitigation actions. The data collected through SIINas can be used for national inventories, carbon trading mechanisms, and both mandatory and voluntary reporting. This platform also needs to be equipped with standardization of calculations and reporting formats that are in accordance with cross-ministerial needs and accompanied by strict SOPs for data protection and management.

In addition, the development of an "Indonesian Green Nickel Standard" is required to govern environmental, social, and governance (ESG) aspects within companies, and to serve as a compliance benchmark in the implementation of decarbonization strategies. This standard must be aligned with existing regulations to facilitate the certification process and recognition of company achievements.

Finally, the establishment of both fiscal and non-fiscal incentive and disincentive schemes is essential. Market-based mechanisms can be implemented by expanding carbon pricing policies to include the nickel industry sub-sector. Meanwhile, non-market approaches may involve encouraging the development of green industrial zones by requiring tenants in the nickel industry to adopt a green nickel standard as a condition for receiving fiscal and non-fiscal incentives. This aligns with Government Regulation No. 20 of 2024, which provides facilities for companies that support the development of a green industry.

8

Implementation of nickel price control in the market

The oversupply of nickel since 2022 has the potential to continue pushing prices downward. At the same time, adequate profit margins are essential for nickel producers to pursue decarbonization efforts while maintaining the financial stability of their operations. Without interventions in nickel and raw material prices, a positive margin can still be achieved in Cluster 1 (up to 23.8 percent) and Cluster 2 (up to 25.2 percent) for the production of one ton of nickel. However, Cluster 2 also shows a negative margin of -37.7 percent due to high hydrogen costs.

Therefore, this roadmap recommends raw material price interventions to maintain the average company margin across all three clusters at above 10 percent. It is important to note, however, that this margin calculation is based on an average NPI price in 2023. As such, the success of this intervention must be accompanied by policies to control nickel price supply.

Through a moratorium on RKEF smelter construction, acceleration of the stainless steel industry, and the establishment of the domestic metal exchange, nickel prices are expected to better reflect domestic market conditions. Additionally, the formation of a state-owned enterprise (SOE) specifically focused on nickel trading and the production of high-grade nickel matte is seen as a key strategy to stabilize prices. This SOE would be tasked with purchasing class II nickel products at a officially designated price during periods of price fluctuation, selling value-added products to the electric vehicle market, or holding inventory until prices recover. These efforts would be further supported by the development of a green nickel standard and low-carbon certification to stimulate demand from domestic end-user sectors such as construction and transportation.

Figure IX.
Eight policy directions toward a low-carbon nickel industry in Indonesia (2025-2045)

Policy Directions for Realizing a Low-Carbon Nickel Industry in Indonesia (2025–2045)

Vision: The nickel industry in Indonesia will reduce GHG emissions by 81% by 2045

Mission: To ensure all facilities supporting the implementation of decarbonization strategy are available, accessible, affordable, with assured quality and safety

8 KEY POLICY DIRECTIONS FOR TRANSFORMING THE LOW-CARBON NICKEL INDUSTRY

1 Transition of electricity system

- **Revise the power generation and grid infrastructure plans** within the RUKN and the RUPTL to accommodate the decarbonization requirements of the nickel industry, while ensuring the seamless execution of these plans
- **Develop an attractive investment ecosystem** to finance power plant construction by implementing regulatory reforms, adjusting electricity tariffs, modifying contract durations, and providing guarantees aimed at mitigating project risk profiles
- **Reform and strengthen the Public-Private Partnership (PPP) mechanism for financing the construction of power plants and grid infrastructure** through improvements in mechanisms and mandates for financing infrastructure

2 Development of an integrated green hydrogen supply chain for clean electricity generation

- **Develop and implement a technical plan for building the green H_2 supply chain** — from hydrogen production, transportation, to clean power generation and distribution to smelters — while securing prospective buyers through off-take agreements
- **Provision of financing schemes and fiscal incentives for supply chain development** through PPP, guarantees, and import duty exemptions for key equipment such as electrolyzers and storage systems
- **Provide targeted subsidies for green H_2 and the clean electricity it generates**, to prevent severe negative margins in Cluster 2, using nickel royalties as a funding source
- **Establish technical and environmental standards for green H_2**

3 Development of Sustainable Biomass Supply Chain for Bioreductant Production

- **Establish technical and environmental standards for biomass and bioreductants,** including stricter enforcement of Energy Plantation Forests (HTE) implementation
- **Establish an attractive benchmark price for sustainable biomass**
- **Provide financing schemes and fiscal incentives for supply chain development** by optimizing private investment models, supported by guarantees and the use of a portion of revenue from palm kernel shell export levies to reduce CAPEX
- **Develop basic infrastructure for biomass supply chain development**, including a national strategy, action plan, KBLI code, regulations on recycling rates, and demand mapping

4 Expansion of Natural Gas Supply for Metallurgical Coal Substitution

- **Revise planning documents and regulatory frameworks supporting natural gas expansion**, including updates to the national gas balance and targets, alongside regulatory reforms to expedite the permitting process for gas terminals
- **Provision of financing schemes and fiscal incentives for the development of natural gas supply** infrastructure by optimizing private investment models, supported by the collection of off-take agreements, provision of guarantees, and import duty exemptions for key equipment such as regasification plants
- **Expansion of the HGBT regulation scope to also include the nickel industry**

5 Expansion of Energy Efficiency Adoption

- **Increase funding flows for energy efficiency projects** by mainstreaming the ESCO mechanism, establishing criteria within OJK's TKBI framework, and developing a catalog containing a list of accessible financing products
- **Development of technical guidelines and a best practice catalog** for the implementation of waste heat recovery in the nickel industry

6 Acceleration of Biodiesel Adoption in Indonesia

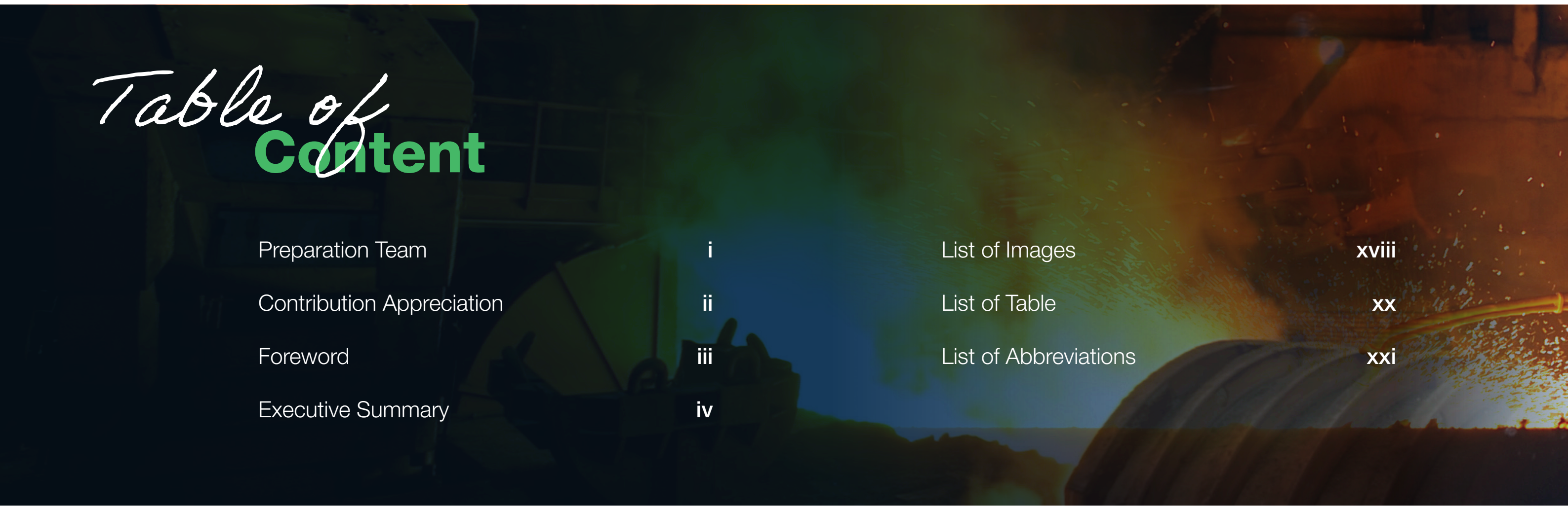
- **Monitor biodiesel market index prices** to prevent extreme fluctuations and price spikes
- **Establish environmental standards for biomass and biodiesel**
- **Ensure a reliable supply of biodiesel for the nickel industry** through off-take agreements
- **Update the national biodiesel blending targets for the post-2025 period**

7 Improving national nickel decarbonization governance

- **Mandatory and gradual implementation of nickel industry decarbonization policies:**
  1. Nickel industries are required to report and reduce emissions (starting no later than 2029)
  2. Carbon trading in the power sector involving the nickel industry (starting no later than 2030)
  3. Carbon trading in the industrial sector involving the nickel industry (starting no later than 2034)
- **Develop a set of governance support instruments for decarbonizing the nickel industry,** such as:
  1. Guidelines for GHG emissions inventory in the nickel industry
  2. Emission reduction targets or performance standards for GHG mitigation efforts in the nickel industry (e.g., ministerial regulations or decrees on roadmaps, emission reporting systems specific to the nickel industry, or the 'Indonesian Green Nickel Standard')
  3. Market-based incentive mechanisms (e.g., carbon pricing)
  4. Non-market-based incentive mechanisms (e.g., fiscal and non-fiscal incentives from industrial estates)
- **Reform the governance system for nickel industry decarbonization** by integrating systems, reforming regulations and infrastructure, and improving inter-ministerial and institutional coordination models to enable more efficient impact assessments, target-setting, strategy formulation, reporting, and performance evaluation in support of achieving decarbonization goals

8 Implementation of nickel price control in the market

- **Establish a mechanism for controlling nickel supply** through:
  1. A moratorium on nickel smelter
- **Establish a mechanism to ensure demand availability for nickel** through:
  1. Development of domestic supply chains for stainless steel and high-grade nickel matte through downstream industrialization
  2. Establishment of emission standards for end products (e.g., buildings)
- **Ensure nickel prices remain stable and at a premium level through the following measures:**
  1. Establishment of the Indonesia Metal Exchange as the benchmark price setter for both conventional and green (premium) nickel
  2. Formation of a Nickel Logistics Agency (Bulog Nikel) or a SOE to manage production and export quotas, as well as to absorb FeNi & NPI for processing into high-grade nickel matte



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List of Abbreviations

A

ADHK	GDP at Constant Prices *(Atas Dasar Harga Konstan)*

B

Bappenas	National Development Planning Agency *Badan Perencanaan Pembangunan Nasional)*
BaU	Business as Usual
BBN	Biofuels *(Bahan Bakar Nabati)*
BF	Blast Furnace
BKPM	Indonesia Investment Coordinating Board *(Badan Koordinasi Penanaman Modal)*
BPDP	The Plantation Fund Management Agency
BPS	Central Statistics Agency *(Badan Pusat Statistik)*
BRIN	National Research and Innovation Agency *(Badan Riset dan Inovasi Nasional)*
BSN	National Standards Agency *(Badan Standardisasi Nasional)*

C

CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CCPP	Combined Cycle Power Plant
CDP	Carbon Disclosure Project
CFPP	Coal-fired Power Plants
CIPP	Comprehensive Investment and Policy Plan
CoW	Contract of Work
CRC	Cold Rolled Coil
CSP	Concentrated Solar Power

D

DAC	Direct Air Capture
DMO	Domestic Market Obligation
DRI	Direct Reduced Iron
DPP	Diesel Power Plant *(Pembangkit Listrik Tenaga Diesel)*

E

EBT	Renewable Energy *(Energi Baru dan Terbarukan)*
EIA	Environmental Impact Analysis
ENDC	Enhanced Nationally Determined Contribution
EPI	Energi Primer Indonesia
ESDM	Energy and Mineral Resources *(Energi dan Sumber Daya Mineral)*
ESG	Environmental, Social, and Governance
ETM	Energy Transition Mechanism
EV	Electric Vehicle

F

FAME	Fatty Acid Methyl Ester
FDI	Foreign Direct Investment
FEED	Front-End Engineering Design
FeNi	Ferronickel
FSC	Forest Stewardship Council
FSRU	Floating Storage and Regasification Unit

G

GDP	Gross Domestic Product
GPP	Geothermal Power Plant (*Pembangkit Listrik Tenaga Panas Bumi*)
GRK	Greenhouse Gases *(Gas Rumah Kaca)*
GWh	Gigawatt Hour

H

HGBT	Specified Natural Gas Prices *(Harga Gas Bumi Tertentu)*
HGNM	High-Grade Nickel Matte
HL	Heap Leach
HPAL	High Pressure Acid Leach
HPP	Hydroelectric Power Plant (*Pembangkit Listrik Tenaga Air*)
HRC	Hot Rolled Coil
HTE	Energy Plantation Forest

I

ICMM	International Council of Mining and Metals
IDO	Industrial Diesel Oil
IEA	International Energy Agency
IIFCL	India Infrastructure Finance Company Ltd
IMIP	Indonesia Morowali Industrial Park
IPP	Independent Power Producer
IPPU	Industrial Process and Product Use
IRMA	The Initiative for Responsible Mining Assurance
ISO	International Organization for Standardization
ISPO	Indonesian Sustainable Palm Oil
IUP	Mining Business License *(Izin Usaha Pertambangan)*
IUP-K	Special Mining Business License *(Izin Usaha Pertambangan Khusus)*
IWIP	Indonesia Weda Bay Industrial Park

J

JETP	Just Energy Transition Partnership

K

KBL	Electric Motor Vehicles
KBLI	Standard Classification of Indonesian Business Fields
Kemenut	Ministry of Forestry/*Kementerian Kehutanan*
Kepmen	Ministerial Decree *(Keputusan Menteri)*

KfW	Germany's state-owned development and investment bank (*Kreditanstalt für Wiederaufbau*)
KLH	Ministry of Environment/*Kementerian Lingkungan Hidup*

L

LCA	Life Cycle Assessment
LCT	Low Carbon Technology
LFP	Lithium Iron Phosphate
LGNM	Low-Grade Nickel Matte
Li-ion	Lithium-ion
LNG	Liquefied Natural Gas
LSPro	Product Certification Body *(Lembaga Sertifikasi Produk)*
LTS-LCCR	Long-Term Strategy for Low-Carbon and Climate Resilience

M

MEBI	Indonesian Biomass Energy Society
MFO	Marine Fuel Oil
MHP	Mixed Hydroxide Precipitate
MIP	Market Index Prices
MMSCFD	Million Standard Cubic Feet per Day
MSMEs	Micro, Small, and Medium Enterprises
MSP	Mixed Sulphide Precipitate
MSW	Municipal Solid Waste
MTSPA	Metric Tons Per Annum
MWH	Megawatt-Hour

N

NCA	Nickel Cobalt Aluminium oxide
NCV	Net Calorific Value
NDC	Nationally Determined Contribution
NMC	Nickel Manganese Cobalt oxide
NPI	Nickel Pig Iron
NPP	Nuclear Power Plants
NZE	Net Zero Emission

O

OESBF	Oxygen-Enriched Smelting Blast Furnace
OJK	Financial Services Authority
OPEX	Operational Expenditure

P

PCAM	Precursor Cathode Active Material
Perda	Regional Regulations *(Peraturan Daerah)*
Permen	Ministerial Regulation *(Peraturan Menteri)*
PKB	Motor Vehicle Tax *(Pajak Kendaraan Bermotor)*
PKS	Oil Palm Mill *(Pabrik Kelapa Sawit)*
PLN	State Electricity Company *(Perusahaan Listrik Negara)*
PLTGU	Gas and Steam Power Plants *(Pembangkit Listrik Tenaga Gas dan Uap)*
PMA	Foreign Investment *(Penanaman Modal Asing)*
PNBP	Non-Tax State Revenue *(Penerimaan Negara Bukan Pajak)*
PPnBM	Luxury Goods Sales Tax (Pajak Penjualan atas Barang Mewah)
PROPER	Public Disclosure Program for Environmental Compliance
PV	Photovoltaic

R

REC	Renewable Energy Certificate
Renstra	Strategic Plan *(Rencana Strategis)*
RHAN	National Hydrogen and Ammonia Roadmap *(Rencana Hidrogen dan Amonia Nasional)*
RKAB	Work Plan and Cost Budget *(Rencana Kerja dan Anggaran Biaya)*
RKEF	Rotary Kiln Electric Furnace
RKL-RPL	Environmental Management Plan-Environmental Monitoring Plan
ROI	Return On Investment
RPJMN	National Medium-Term Development Plan *(Rencana Pembangunan Jangka Menengah Nasional)*
RPJPN	National Long-Term Development Plan
RSPO	Roundtable on Sustainable Palm Oil
RTH	Green Open Space *(Ruang Terbuka Hijau)*
RTRW	Regional Spatial Plan *(Rencana Tata Ruang Wilayah)*
RUKN	National Electricity General Plan *(Rencana Umum Ketenagalistrikan Nasional)*
RUPTL	Electricity Supply Business Plan *(Rencana Usaha Penyediaan Tenaga Listrik)*

S

SIINas	Socialization of the National Industrial Information System *(Sosialisasi Sistem Informasi Industri Nasional)*
SMM	Shanghai Metals Market
SNI	Indonesian National Standards *(Standar Nasional Indonesia)*
SOEs	State-Owned Enterprises
SOP	Standard Operating Procedures
SPKLU	Public Electric Vehicle Charging Station
SPP	Solar Power Plant *(Pembangkit Listrik Tenaga Surya)*
STAL	Step Temperature Acid Leach
SYNERGY	Energy Conservation Information System

T

tCO_2e	Tonnes of carbon dioxide equivalent
TJ	Terajoule
TKDN	Domestic Component Levels *(Tingkat Komponen Dalam Negeri)*
t-Ni	Tonnes of Nickel
TRL	Technology Readiness Level
TWh	Terawatt-Hour

U

USGS	United States Geological Survey

V

VAT	Value Added Tax
VM	Volatile Matter

W

WPP	Wind Power Plant *(Pembangkit Listrik Tenaga Bayu)*

CHAPTER 01

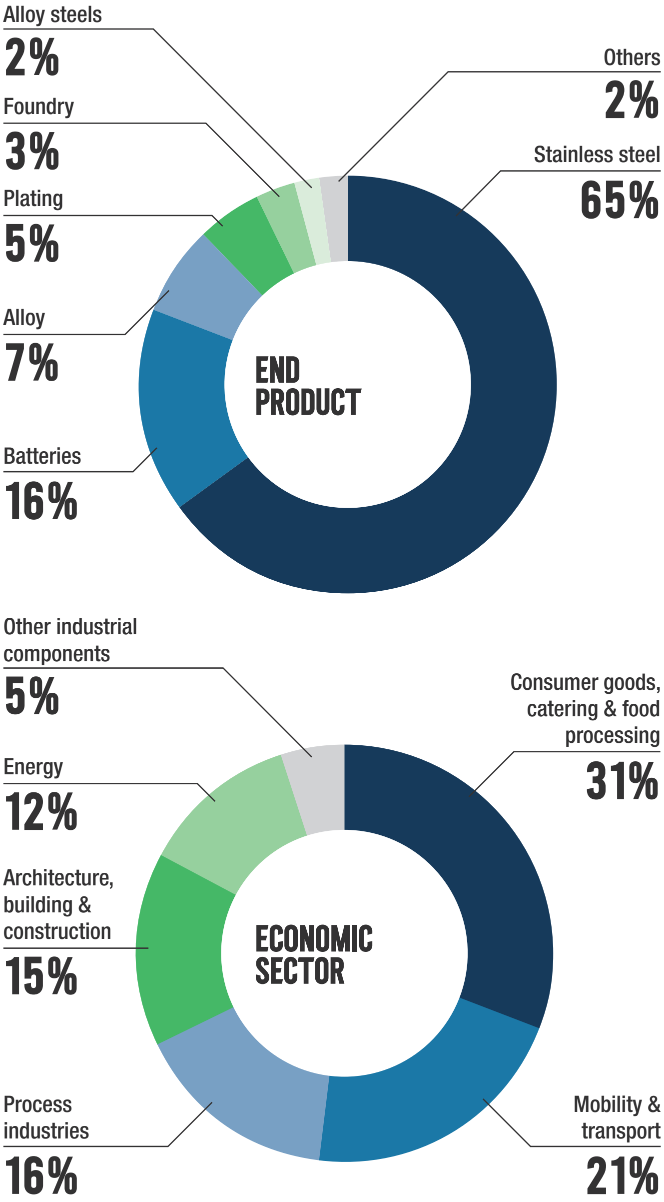
INTRODUCTION

1.1

GLOBAL NICKEL LANDSCAPE

Nickel is a key material used in a wide range of technologies across manufacturing industries, power generation, and everyday life. Generally, nickel is used as a stainless steel material and an alloy. In 2023, stainless steel production alone accounted for 65% of global nickel consumption. In addition to being corrosion-resistant, nickel-based materials are also strong, scratch-resistant, and easy to clean, making them widely used in consumer goods such as kitchenware and electronic devices. Thanks to these properties, nickel is also commonly used in industrial machinery components and construction materials.

Figure 1.
World nickel usage by product type and sector



Source: Nickel Institute (2023)

In recent years, there has also been a growing demand for nickel in the production of LCT, in line with global efforts to achieve net zero emissions. Nickel is a critical material in various LCT applications, such as electric vehicle batteries and specific components in renewable energy power plants, including WPP, piping in GPP, and electrolysers for hydrogen production. For example, in electric vehicle batteries, nickel helps increase energy density and power efficiency. In turbines and piping systems, nickel is essential for enhancing corrosion resistance and extending product lifespan.

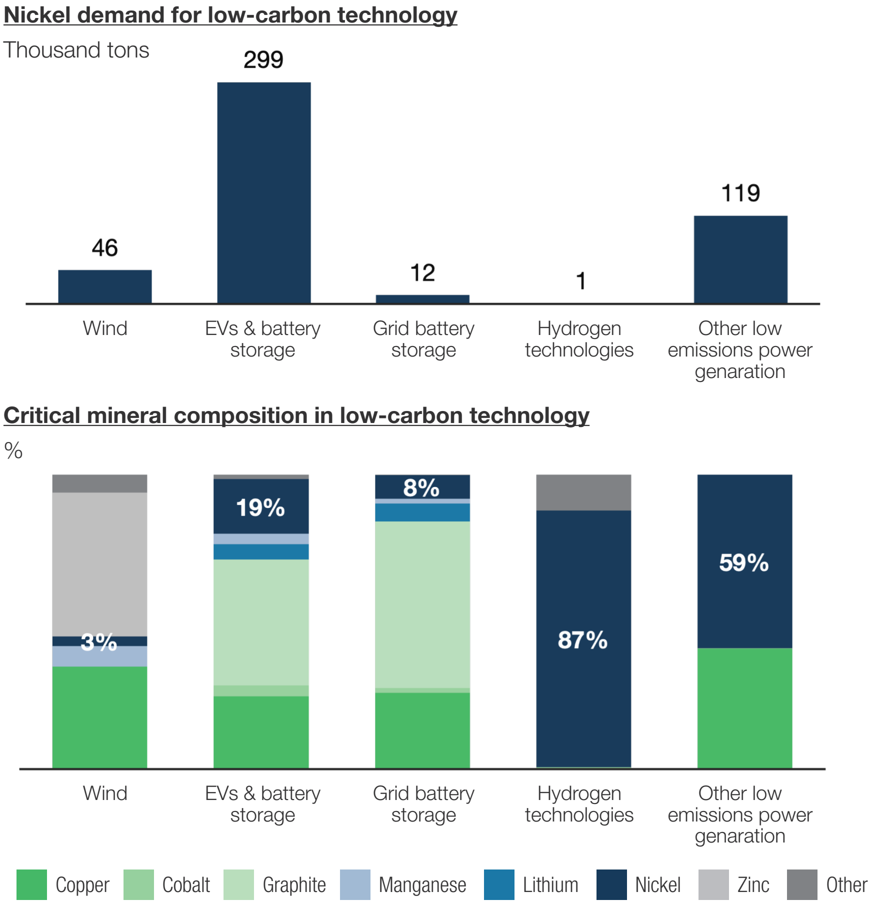
Figure 2.
Use of critical minerals as materials in low-carbon technologies

Clean Energy Technologies	Copper	Cobalt	Nickel	Lithium	Rare Earth Elements (REE)	Chromium	Zinc	Logam Platina (PGMs)	Aluminum
Solar PV	●								●
Wind	●		●		●	●	●		●
Hydro	●					●	●		●
Concentrated Solar Power (CSP)	●		●			●	●		●
Bioenergy	●		●				●		●
Geothermal			●			●			
Nuclear	●					●			
Electricity networks	●								
EVs & battery storage	●	●	●	●	●				●
Hydrogen			●		●			●	●

Source: Addressing Vulnerabilities in the Supply Chain of Critical Minerals, 2023

Among the five types of low-carbon technologies shown in **Figure 3**, the largest demand for nickel comes from the production of electric vehicle batteries. According to 2023 data from the International Energy Agency (IEA), a total of 299,000 tons of nickel was used in the production of nickel-based lithium-ion (Li-ion) batteries, specifically those with nickel cobalt aluminium oxide (NCA) and nickel manganese cobalt oxide (NMC) cathodes. In addition, the power generation sector also requires a significant supply of nickel, with 46,000 tons used for WPP and 119,000 tons for a combination of other power plants, including Nuclear Power Plant (NPP), Hydro Power Plant (HPP), Geothermal Power Plant (GPP), and Concentrated Solar Power (CSP). With nickel accounting for 59 percent of the total use across these technologies, it is important to anticipate a growing demand for nickel driven by the expansion of low-emission power generation.

Figure 3.
Critical mineral demand for low-carbon technologies in 2023

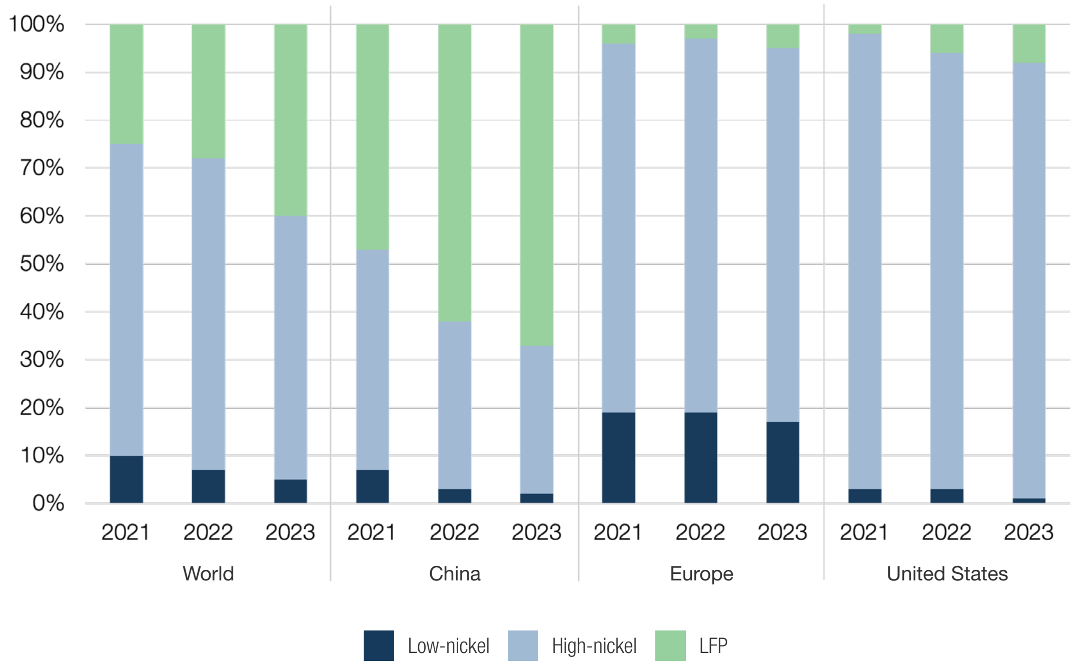


Source: IEA (2024)

Although the use of nickel continues to expand, there is competition from other types of minerals that could hinder the growth of the nickel market in the future. One example is the competition between electric vehicle batteries with nickel-based cathodes (NMC & NCA) and lithium (Lithium Iron Phosphate/ LFP). Unlike NMC batteries that contain nickel in varying degrees, LFP batteries do not contain nickel at all. As a result, LFP batteries have lower energy density. This means that for the same battery size, the driving range of an electric vehicle using LFP is shorter compared to one using NMC. However, LFP batteries have their own advantages, including safety, longer lifespan, and lower cost. This competitive price point is due to the abundance of lithium, iron, and phosphate, compared to nickel and cobalt which are more limited and concentrated in certain regions. As a result, the market share of LFP batteries increased from 28% to 40% during the 2021–2023 period. This growth trend has been driven by high adoption in the Chinese market. The development of LFP battery technology and the expansion of its manufacturing integrated with the automotive industry have made LFP products highly competitive, becoming one of the main drivers behind the increase in LFP market share.

Nevertheless, the European and U.S. markets are still dominated by nickel-based batteries, with LFP adoption progressing more slowly. In 2023, nickel-based batteries still accounted for more than 90% of the market share in both regions. This indicates a market preference for electric vehicles with high performance in terms of driving range and the ability to withstand extreme weather conditions.

Figure 4.
Share of battery capacity of electric vehicle sales by chemistry and region, 2021–2023

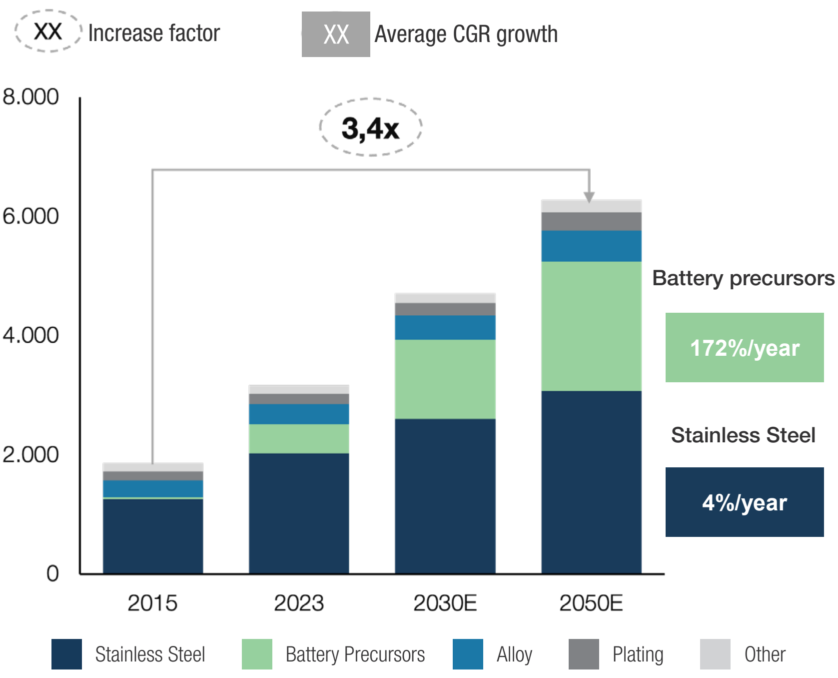


Source: IEA (2024)

Despite the rise of LFP batteries, the demand for nickel as a raw material for electric vehicle batteries is projected to grow rapidly, at an average rate of 172 percent per year through 2050. This demand is driven by countries' efforts to transition to clean energy. For example, the European Union has committed to ensuring that all newly registered vehicles in its region are zero-emission by 2035. To support electric vehicle adoption, incentive mechanisms such as tax exemptions and purchase subsidies are being implemented, with amounts varying by country. Outside the EU, countries such as China, Thailand, Indonesia, and the United States also offer similar incentives.

In contrast, demand growth for nickel as a stainless steel material is projected to average only 4 percent per year. The demand for stainless steel is also influenced by the global market's dependence on the Chinese economy. China plays a central role in determining the stability of the stainless steel market, as it is the world's largest producer, consumer, and exporter. A weakening Chinese economy has affected the property and infrastructure sectors, resulting in significant imbalances between supply and demand. Nonetheless, despite economic challenges, the Chinese government continues efforts to stabilize the steel industry through price controls, production capacity management, and increased export allowances.

Figure 5.
Global nickel demand projections by product type
Kt Ni-eq



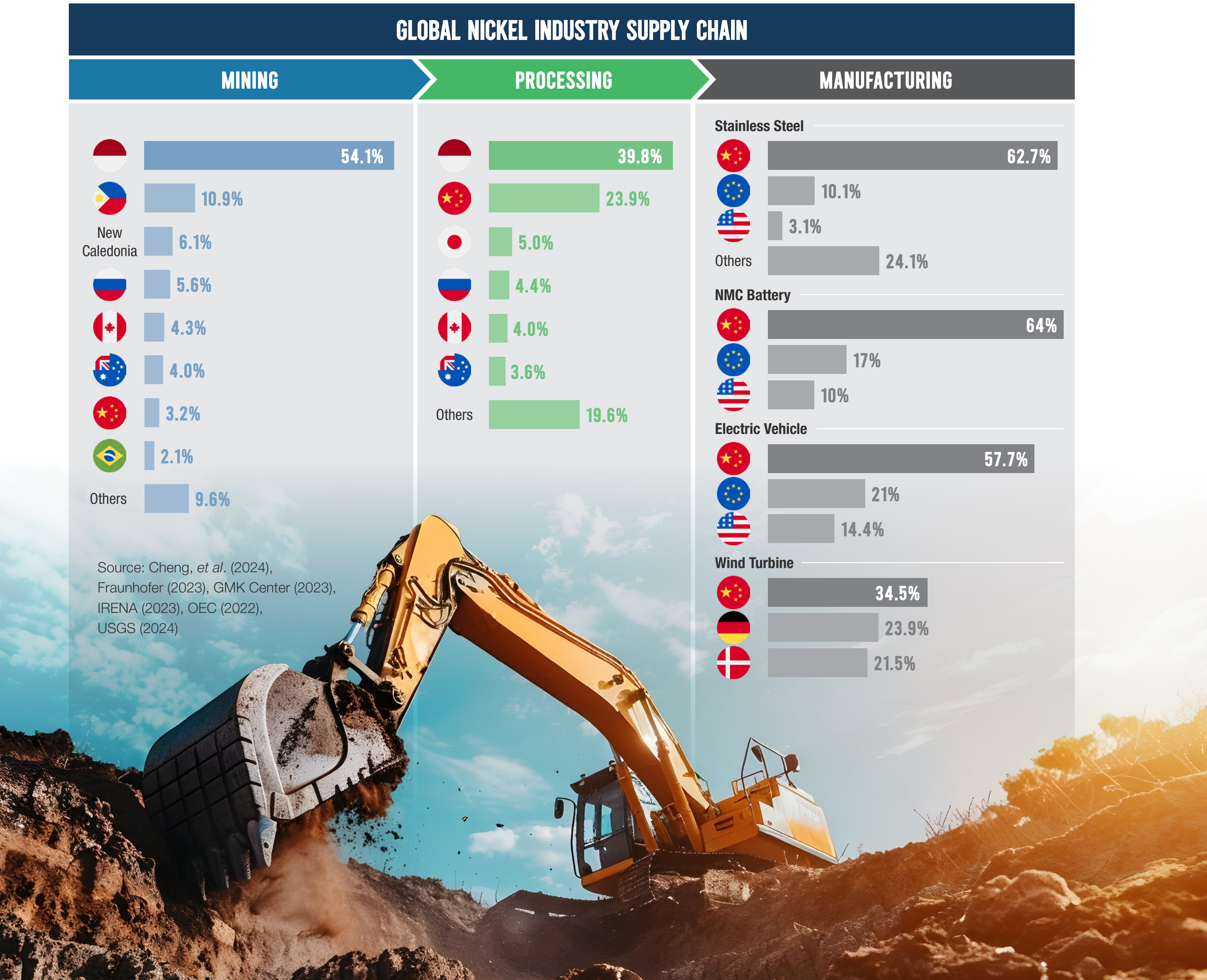
Nickel demand is met by various producing countries along the nickel supply chain, ranging from mining and processing to end-product manufacturing and recycling. According to 2024 data from the United States Geological Survey (USGS), Indonesia holds the world's largest nickel reserves, amounting to 55 million tons or 42.3 percent of the global total. Indonesia also dominates global nickel ore mining, accounting for 60.1 percent of total production. Other countries with significant nickel reserves include Australia, Brazil, Russia, New Caledonia, and the Philippines.

Once mined, nickel ore is processed into several semi-finished nickel products, such as ferronickel, nickel pig iron (NPI), mixed hydroxide precipitate (MHP), matte, and others. Combined, these products make up Indonesia's contribution of 39.8 percent to global production, the majority of which consists of ferronickel and NPI. China ranks second in global nickel processing capacity at 23.9 percent, despite having relatively limited nickel reserves. Most of the nickel processed in China is also turned into ferronickel and NPI, used primarily in stainless steel production to support its manufacturing and real estate sectors.

Further down the supply chain, semi-finished nickel products are processed into end products such as stainless steel, electric vehicle batteries, and metal alloys. China is also the leading producer in this downstream segment. It dominates global production capacity for nickel-based end products, including stainless steel and low-carbon technologies such as NMC batteries, electric vehicles, and wind turbines. Following China, the European Union and the United States also play significant roles in the downstream nickel supply chain. However, their positions are far behind China's, which has rapidly expanded its global reach across the entire nickel supply chain—from upstream to downstream.

As the world's largest producer of nickel ore and semi-finished nickel products, Indonesia has not yet become a major player in the downstream supply chain. The Indonesian nickel industry remains export-oriented, with most of its semi-finished nickel products ending up in China, Japan, and Europe. On the other hand, there is a significant opportunity for Indonesia to move further into the nickel-based battery and stainless steel industries. By 2050, demand for nickel from both of these industries is projected to double compared to 2023. Indonesia should be able to leverage the imbalance in reserve ownership between itself and other countries to create long-term economic benefits.

Figure 6.
Global distribution of nickel production capacity across supply chains



Source: Cheng, *et al*. (2024), Fraunhofer (2023), GMK Center (2023), IRENA (2023), OEC (2022), USGS (2024)

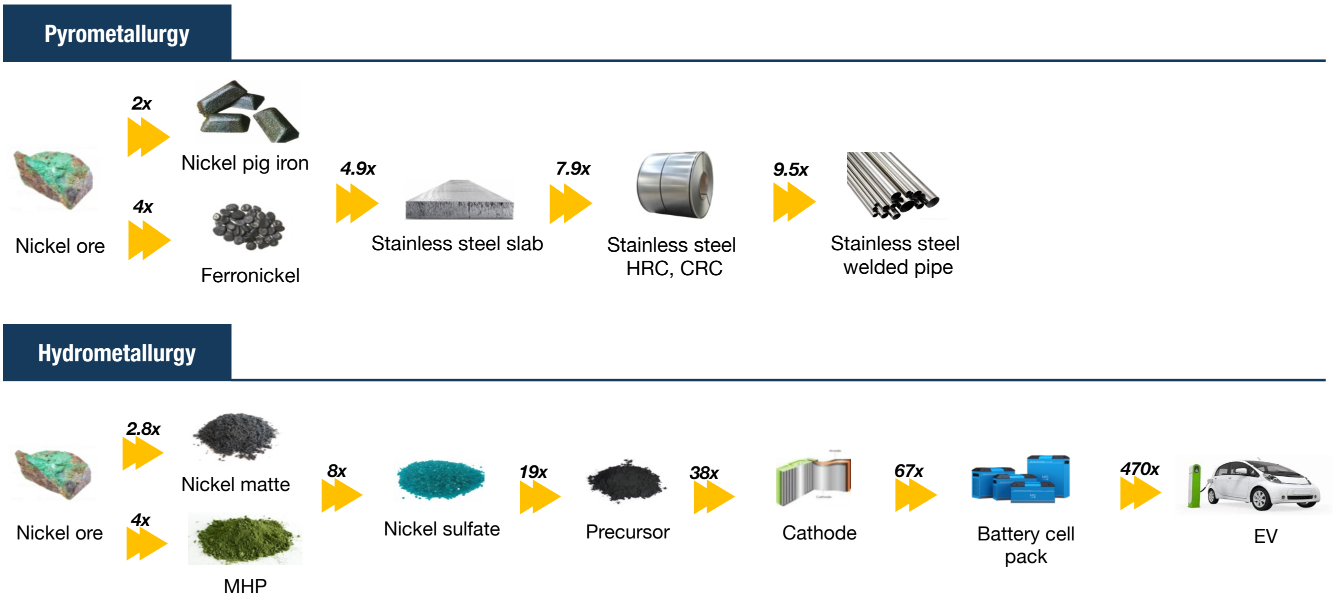
1.2

PROGRESS OF NICKEL DOWNSTREAMING IN INDONESIA

The rapid development of Indonesia's nickel industry began with the implementation of downstream industrial policy through Ministry of Energy and Mineral Resources Regulation (Permen ESDM) No. 11 of 2019, which banned the export of nickel ore with a content of less than 1.7% starting January 1, 2020. The government saw an opportunity in the rising global demand for nickel derivative products and committed to producing high value-added nickel derivatives domestically by developing two major industrial ecosystems: the stainless steel value chain and the electric vehicle battery value chain.

The stainless steel industry, which produces hot rolled coils (HRC) and cold rolled coils (CRC), has the potential to create value added up to 9.5 times greater than raw nickel ore, with projected demand reaching USD 365 billion by 2045. Meanwhile, the electric vehicle battery industry could generate value added up to 67 times greater, with projected demand reaching USD 5.91 trillion by 2045. The Ministry of Investment and Downstreaming (BKPM) has projected that by the end of 2045, the downstreaming policy will contribute USD 43.2 billion annually to GDP, attract USD 127.9 billion in investment, create 357,000 jobs, and increase national industrial capacity. This strategic effort is a strong step toward enhancing domestic value addition, enabling Indonesia not only to be a raw material supplier to other countries, but also to gain greater economic benefits.

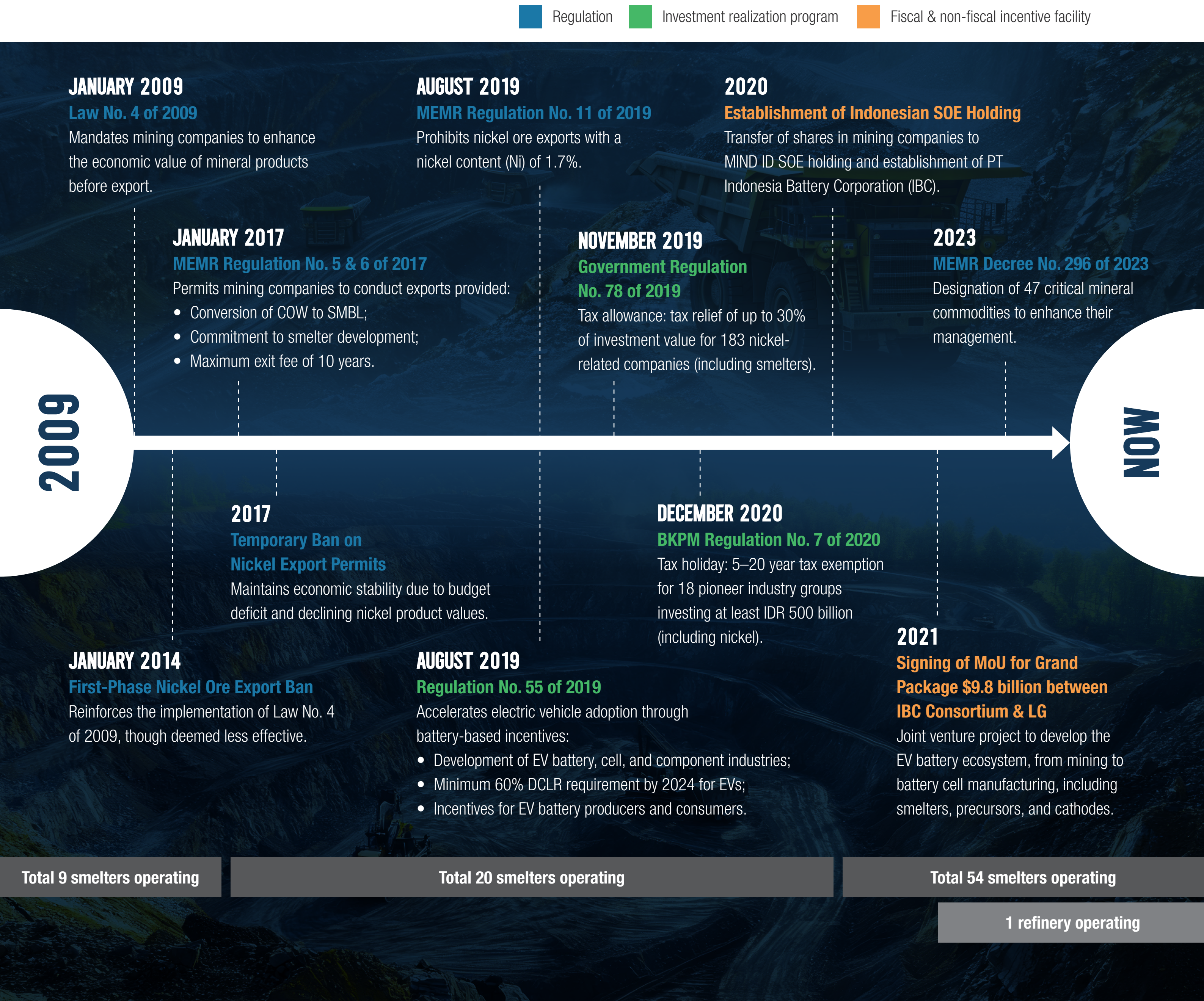
Figure 7.
Increase in the added value of nickel products due to downstream



To realize the development of the two industrial ecosystems, the government issued a variety of supporting policies. In the supply sector, examples of policies are: 1) issuing regulations that require the processing and refining of nickel ore domestically and setting a minimum TKDN requirement of 60% starting in 2024 for electric motor vehicles (KBL); 2) running an investment realization program that will allow for a surge in the construction and operation of 34 new nickel smelters since 2020 and the construction of one electric vehicle battery plant; and 3) providing fiscal incentive facilities in the form of providing tax holidays and tax allowances for the new nickel industry in Indonesia as well as exemption from Luxury Goods Sales Tax (PPnBM) for imported electric vehicles (on the condition that they are willing to build an electric vehicle factory in Indonesia).

In the demand sector, many policy examples focus on shaping demand for electric vehicles in the domestic market through: 1) the imposition of a Motor Vehicle Tax (PKB) of 0%; 2) 10% VAT discount for electric cars and buses (so that VAT on the purchase of electric cars is only 1%); 3) Electricity charging fee waivers at SPKLU; and 4) exemption from certain road use restrictions.

Gambar 8.
Downstream policy timeline of the nickel industry in Indonesia



🟦 Regulation 🟩 Investment realization program 🟧 Fiscal & non-fiscal incentive facility

2009

JANUARY 2009
Law No. 4 of 2009
Mandates mining companies to enhance the economic value of mineral products before export.

JANUARY 2014
First-Phase Nickel Ore Export Ban
Reinforces the implementation of Law No. 4 of 2009, though deemed less effective.

JANUARY 2017
MEMR Regulation No. 5 & 6 of 2017
Permits mining companies to conduct exports provided:
- Conversion of COW to SMBL;
- Commitment to smelter development;
- Maximum exit fee of 10 years.

2017
Temporary Ban on Nickel Export Permits
Maintains economic stability due to budget deficit and declining nickel product values.

AUGUST 2019
MEMR Regulation No. 11 of 2019
Prohibits nickel ore exports with a nickel content (Ni) of 1.7%.

AUGUST 2019
Regulation No. 55 of 2019
Accelerates electric vehicle adoption through battery-based incentives:
- Development of EV battery, cell, and component industries;
- Minimum 60% DCLR requirement by 2024 for EVs;
- Incentives for EV battery producers and consumers.

NOVEMBER 2019
Government Regulation No. 78 of 2019
Tax allowance: tax relief of up to 30% of investment value for 183 nickel-related companies (including smelters).

2020
Establishment of Indonesian SOE Holding
Transfer of shares in mining companies to MIND ID SOE holding and establishment of PT Indonesia Battery Corporation (IBC).

DECEMBER 2020
BKPM Regulation No. 7 of 2020
Tax holiday: 5–20 year tax exemption for 18 pioneer industry groups investing at least IDR 500 billion (including nickel).

2021
Signing of MoU for Grand Package $9.8 billion between IBC Consortium & LG
Joint venture project to develop the EV battery ecosystem, from mining to battery cell manufacturing, including smelters, precursors, and cathodes.

2023
MEMR Decree No. 296 of 2023
Designation of 47 critical mineral commodities to enhance their management.

NOW

Total 9 smelters operating

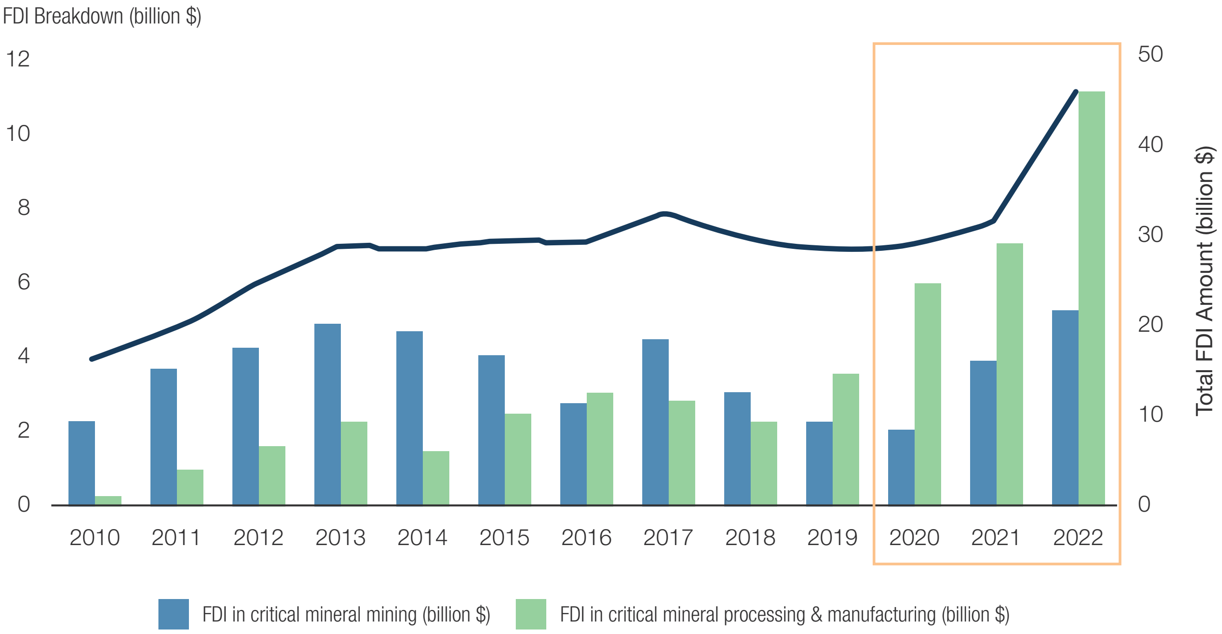
Total 20 smelters operating

Total 54 smelters operating

1 refinery operating

This policy package has yielded positive results. The first benefit is that realized foreign direct investment (FDI) in the critical minerals subsector in Indonesia increased by 179% compared to 2019, before the downstreaming policy was intensified. For seven consecutive years, the mining and basic metal industries have consistently ranked among the top three sectors attracting the most investment, with the critical minerals subsector contributing more than 90% of that investment. Between 2019 and 2022, investment in the critical mineral mining sector increased by approximately 1.3 times, while investment in critical mineral processing rose by about twofold due to the requirement to build new smelters for the domestic processing and refining of nickel ore.

Figure 9.
Realization of foreign investment in Indonesia for the critical minerals subsector, 2010–2022

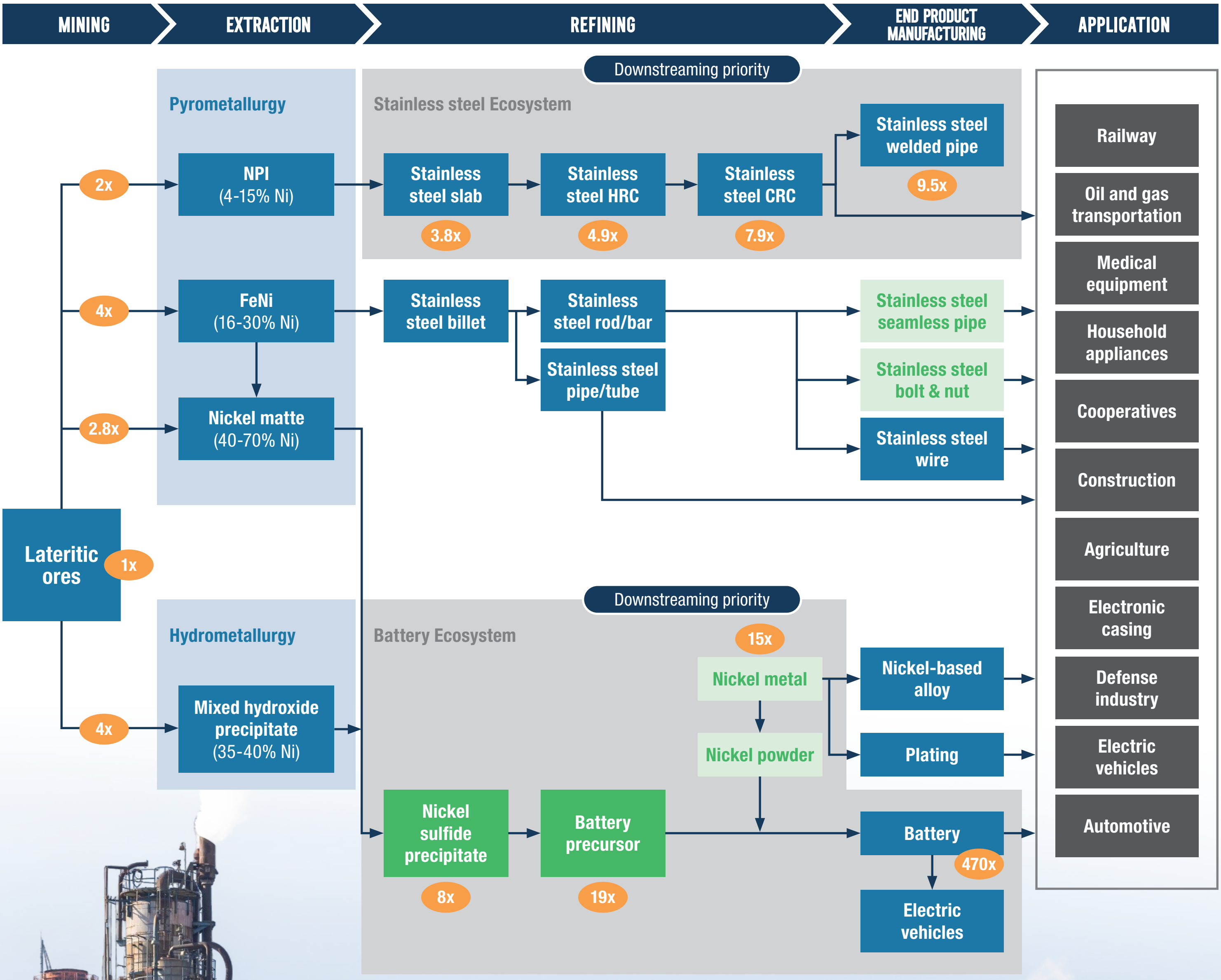


The second benefit is the expansion of Indonesia's nickel industry value chain. The stainless steel ecosystem is now supported by a mining sector producing upstream saprolite nickel ore, a midstream sector producing FeNi and NPI, and a manufacturing sector producing various downstream stainless steel products such as hot rolled coil (HRC), cold rolled coil (CRC), pipes, and rods/bars/wires. By 2027, Indonesia's stainless steel production capacity is projected to reach 7 million tons per year (SMM, 2024), a 209% increase compared to the production capacity in 2019.

At the same time, progress in the battery ecosystem has not been as rapid. Currently, the electric vehicle battery ecosystem consists of a mining sector producing upstream limonite nickel ore and a midstream sector producing MHP and nickel matte. Indonesia already has a manufacturing industry producing electric vehicle batteries (with a production capacity of 10 GWh/year), but one additional type of industry is still needed to bridge the gap between midstream products and batteries—namely, the nickel sulphate and battery precursor industries. At present, these industries are still operating at limited scale, resulting in suboptimal upstream-downstream integration in the EV battery ecosystem and an inability to meet expected production volumes.

Figure 10.
Indonesian nickel industry trees

🟦 Operating 🟩 Operating at certain scale ⬜ Not yet operating ⬛ Sector 🟧 Value-added



Source: Kementerian Investasi (2021), Kementerian Perindustrian (2023).

Figure 11.
Existing and planned nickel facilities by product and development phase, 2010-2024

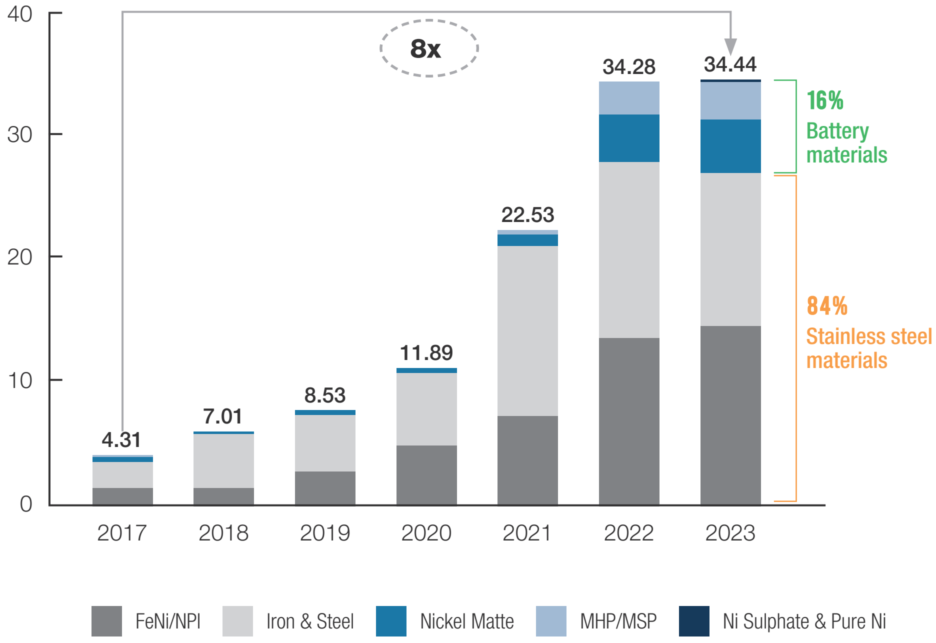
	NICKEL PRODUCT	OPERATION	CONSTRUCTION
	Nickel Ore (Limonite & Saprolite)	368	
Pyrometallurgy	FeNi & NPI	46	71
	Stainless Steel Products (slab, HRC, CRC)	5	0
	Stainless Steel Pipe	5	0
Hydrometallurgy	Nickel Matte	3	24
	MHP	4	23
	Nickel Sulphate	1	10
	Battery Precursor	2	0
	Battery	1	1
	Electric Vehicle	51	1

■ Mining ■ Extraction ■ Intermediate goods ■ End product

The third benefit is the significant growth in Indonesia's nickel product exports, both in terms of volume and value. In 2023, exports of nickel-derived products increased eightfold compared to 2017, with noticeable diversification in the product range—particularly in battery component materials such as nickel matte, MHP/MSP, and nickel sulphate. Going forward, policy efforts should focus on developing the battery and electric vehicle industries to ensure Indonesia captures greater added value from its nickel resources.

Figure 12.
Indonesia's exports of nickel derivatives (2017-2023)

Billion USD



1.3

NICKEL DOWNSTREAMING AND THE VISION OF A GOLDEN INDONESIA 2045

The Government of Indonesia, through the Ministry of National Development Planning (PPN/Bappenas), has enacted Law No. 59 of 2024 on the National Long-Term Development Plan (RPJPN) 2025–2045. Based on this document, Indonesia has adopted the Vision of Golden Indonesia 2045, which is defined as "A United, Sovereign, Advanced, and Sustainable Unitary State of the Republic of Indonesia." This vision is built upon Indonesia's fundamental development capital—including social capital and natural resource wealth—and global megatrends, such as shifting geopolitical dynamics, climate change, and technological advancements.

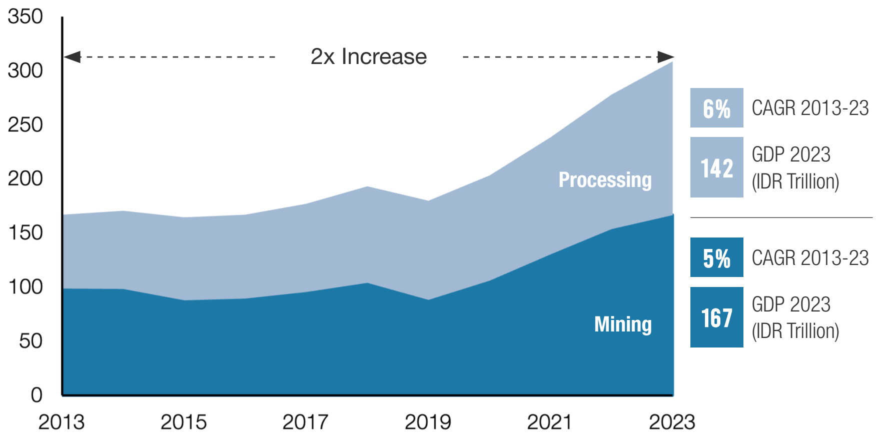
To realize this vision, the government has identified 13 transformative efforts (game changers), one of which is the downstream development of industries based on Indonesia's leading natural resources. In the mineral sector, nickel has been designated a priority commodity due to Indonesia's status as the country with the largest known reserves and the global energy transition trend, which demands large volumes of nickel for the production of batteries, wind turbines, and stainless steel. The downstreaming of nickel aims to increase added value, industrial complexity, competitiveness, and technological advancement.

Figure 13.
The main goal of the Golden Indonesia 2045 vision

				2025 BASELINE	**2045 TARGET**
	01	Per capita income equivalent to developed nations	GNI Per Capita (USD)	5,500–5,520	**30,300**
			Maritime GDP Contribution (%)	8.1	**15.0**
			Manufacturing GDP Contribution (%)	20.8	**28.0**
					Source: World Bank, BPS, Bappenas
	02	Declining poverty and reduced inequality	Poverty Rate (%)	7.0–8.0	**0.5–0.8**
			Gini Ratio (index)	0.379–0.382	**0.290–0.320**
			Eastern Indonesia GRDP Contribution (%)	21.4	**28.5**
					Source: BPS, Bappenas
	03	Enhanced leadership and influence in the international arena	Global Power Index (ranking)	34 (2023)	**Top 15**
					Source: Pareto Economics, Bappenas
	04	Increased human capital competitiveness	Human Capital Index (index)	0.56	**0.73**
					Source: World Bank, Bappenas
	05	Declining GHG emission intensity toward net zero emission	GHG Emission Intensity Reduction (%)	38.6	**93.5**
			Environmental Quality Index	76.49	**83.0**
					Source: KLHS, Bappenas

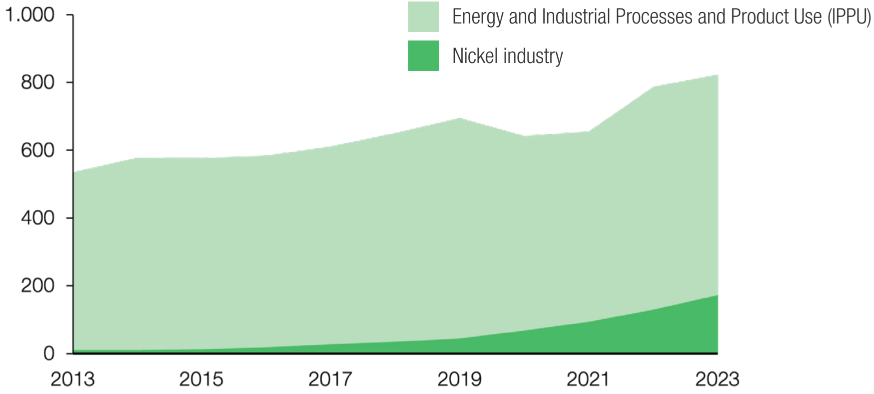
The critical mineral downstreaming program, particularly for nickel, plays a vital role in achieving the Vision of Golden Indonesia 2045, especially with respect to the first and second national goals (see Figure 13). Nickel downstreaming can drive both national and regional economic development by mobilizing investment, which in turn creates jobs and generates added value within the country. This downstreaming effort also produces wide-reaching economic and social impacts across various sectors, including coal mining, logistics services, and Micro, Small, and Medium Enterprises (MSMEs). Since the implementation of the downstreaming policy in 2020, coal consumption in the pyrometallurgy industry has quadrupled, and nickel export value has increased tenfold. In addition, nickel production activities have created spillover effects for local MSMEs, which supply daily needs for workers in the surrounding areas.

Figure 14.
Economic impact of nickel downstream policy
Real GDP, Trillion Rupiah



Within 10 years, the total economic output from the base metals sector has almost doubled from 167 trillion in 2013 to 307 trillion rupiah in 2023. Most of the GDP increase was generated after the implementation of the ban on nickel ore exports in early 2020. The increase in revenue certainly increases state revenue, both through taxes and PNBP/ royalties, as well as increasing the country's foreign exchange through exports. For example, in 2020, the nickel sector contributed 2.9 trillion rupiah in state revenue in the form of PNBP. Three years later, there was a fourfold increase to 13.8 trillion Rupiah. The contribution of the nickel sector to the country's economy is projected to continue to increase along with the construction of new smelters followed by mining expansion.

Figure 15.
Climate impact of nickel downstream policy
GHG Emissions, Million Tons CO_2e



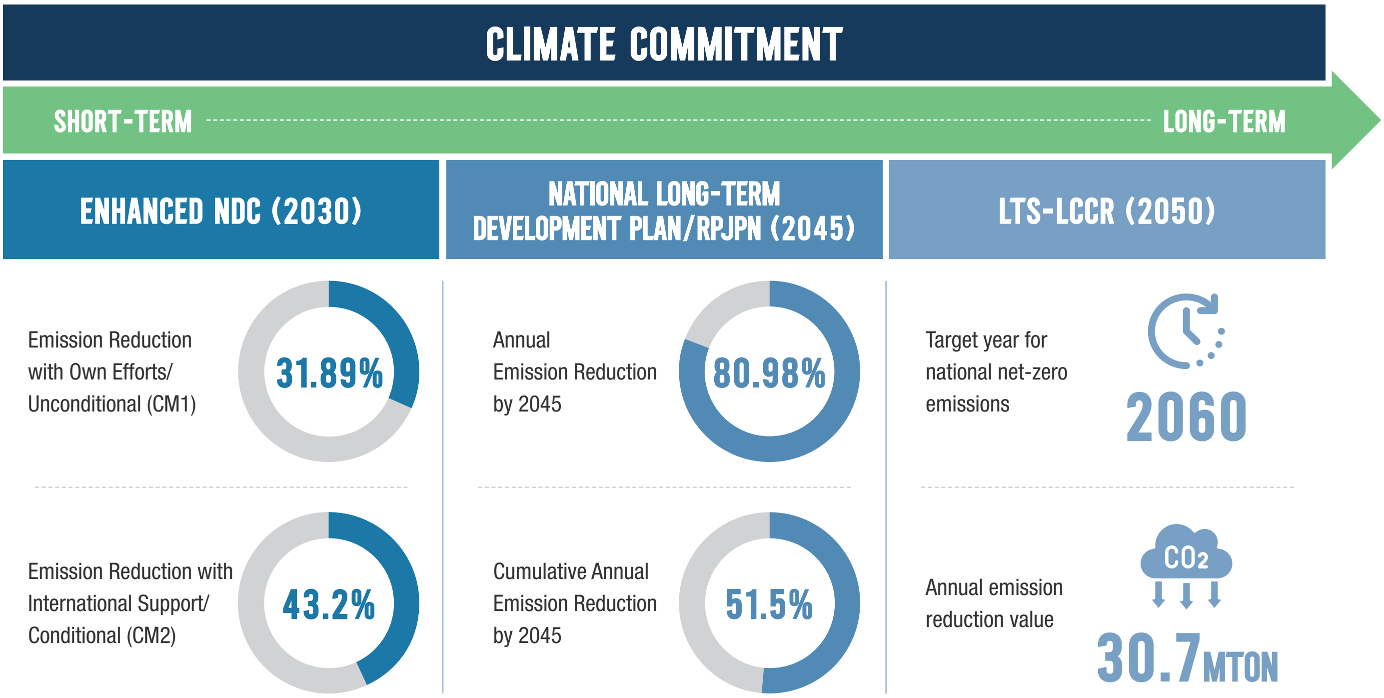
Total nickel industry emissions (% energy sector & IPPU)	1.8	2.1	4.4	6.5	14.2	21.0

However, at the same time, the rapid development of Indonesia's nickel industry has resulted in significant GHG emissions. According to this study, total GHG emissions from the Indonesian nickel industry in 2023 reached 170.2 million tons of CO_2e, equivalent to 21.0% of national GHG emissions in the energy and Industrial Process and Product Use (IPPU) sectors. This figure is remarkably high compared to estimated GHG emissions in 2013, which were 9.8 million tons of CO_2e. Of the 160.4 million ton increase, around 64% has occurred since 2020. This underscores the substantial climate impact of downstreaming policies and the urgent need for mitigation.

In addition to production capacity expansion, the rise in GHG emissions is also driven by the high energy and emissions intensity of nickel processing. This intensity is largely determined by the type of processing technology used and the energy source. The RKEF method is the most widely used nickel processing technology in Indonesia. In 2023, 91% of Indonesia's nickel products—such as NPI, ferronickel, and nickel matte—were produced through pyrometallurgical processes, dominated by RKEF. This method is among the most emission-intensive, especially in Indonesia where coal remains the dominant primary energy source. According to this study, producing one ton of refined nickel using RKEF generates 7 to 10 times more GHG emissions than other technologies such as flash smelting, High Pressure Acid Leaching (HPAL), and bioleaching.

If left unaddressed, the increase in GHG emissions due to the downstreaming of the nickel industry could jeopardize the achievement of Indonesia's climate targets outlined in the Nationally Determined Contribution (NDC), the RPJPN, and the Long-Term Strategy for Low-Carbon and Climate Resilience (LTS-LCCR). In the Enhanced NDC (ENDC), Indonesia aims to reduce GHG emissions by at least 31.9% unconditionally and 43.2% with international support by 2030. In the long term, Indonesia also targets an emissions reduction of 80.98% by 2045 as mandated in the RPJPN Law. This target aligns with the LTS-LCCR goal to reach Net Zero Emissions (NZE) no later than 2060.

Figure 16.
Indonesia's climate commitment



CHAPTER

02

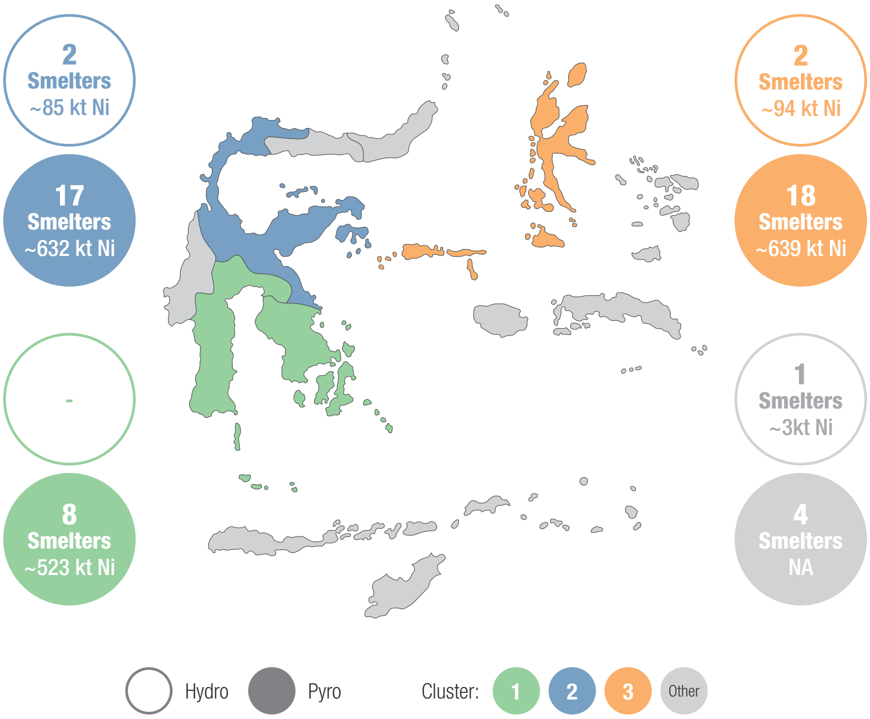
ENERGY AND EMISSIONS PROFILE

The scope of this roadmap is focused on the nickel mining and primary extraction sub-sector in three regional clusters: Central Sulawesi (Cluster 1), North Maluku (Cluster 2), and Southeast and South Sulawesi (Cluster 3). This focus is based on the current condition of the nickel industry, which is dominated by ore production and the processing of ore into intermediate (semi-finished) products. In addition, nearly all nickel production facilities, such as mines and smelters, are located in these regions.

In 2023, which serves as the base year for this roadmap, there were 300 active Mining Business Permits (IUPs) and 51 operational processing units or smelters. Of these 51 smelters operating in 2023, nearly all are located in Sulawesi and Maluku—regions where nickel ore reserves are found (see **Figure 17**).

In terms of production volume, the mining and primary extraction sub-sector produced 175.6 million tons of nickel ore and 1.97 million tons of Ni-eq contained in semi-finished products such as Nickel Pig Iron (NPI), ferronickel, nickel matte, and Mixed Hydroxide Precipitate (MHP).

Figure 17.
Number of nickel smelters and their production capacity in 2023

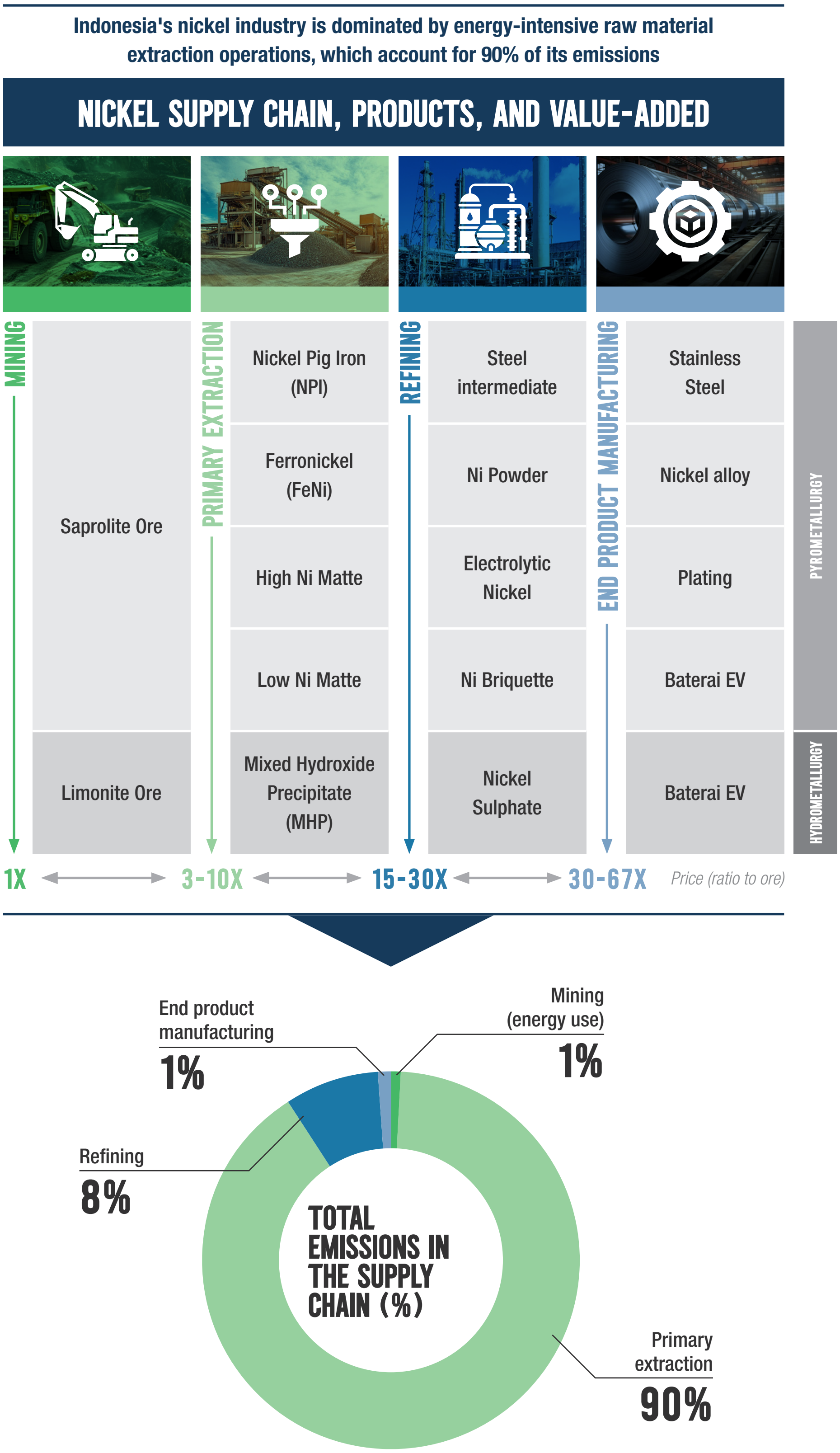


Source: Analisis WRI Indonesia

In contrast, the downstream nickel industry remains underdeveloped compared to the upstream segment (mining and smelting). Among the various refined nickel products (see **Figure 18**), only stainless steel slab and nickel sulphate were produced in Indonesia as of 2023. For stainless steel, six companies operated with a maximum production capacity of 6.6 million tons, equivalent to 264 thousand tons of pure nickel. For nickel sulphate, there was only one company with a capacity of 16 thousand tons Ni-eq. In total, this amounts to 280 thousand tons Ni-eq of refined products, or only 14.2% of the total primary nickel produced in Indonesia.

Similarly, the end-product manufacturing sub-sector remains relatively limited in Indonesia. For stainless steel end-products such as hot rolled coil (HRC) and cold rolled coil (CRC), only five manufacturing companies exist. In the case of battery end-products, there were no factories using Indonesian nickel as input material in 2023. The relatively small scale of production in the refining and end-product manufacturing sub-sectors—combined with the fact that these processes are not as energy-intensive as mining and smelting—places them outside the scope of this roadmap.

Figure 18.
Nickel industry supply chain emission profile in Indonesia



Indonesia's nickel industry is dominated by energy-intensive raw material extraction operations, which account for 90% of its emissions

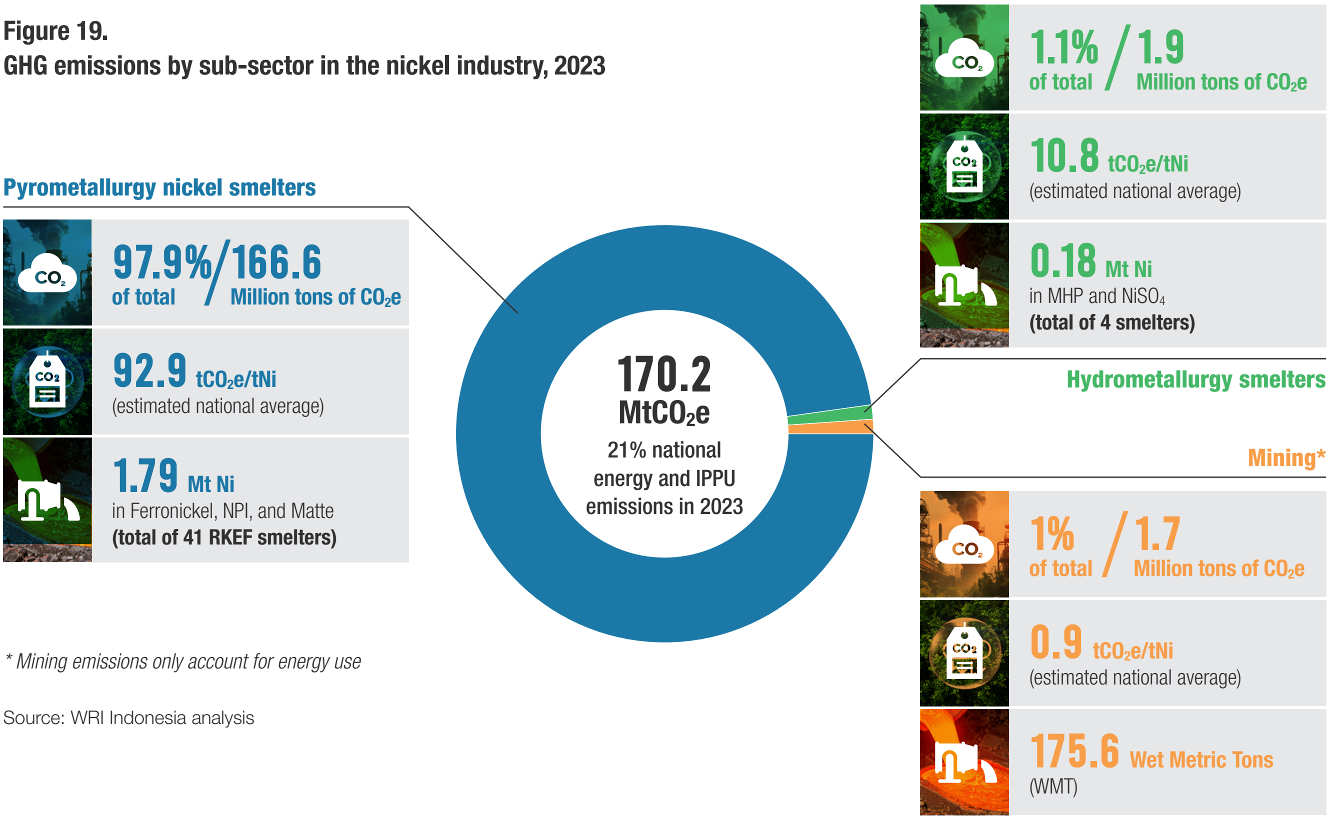
NICKEL SUPPLY CHAIN, PRODUCTS, AND VALUE-ADDED

MINING	PRIMARY EXTRACTION	REFINING	END PRODUCT MANUFACTURING	
Saprolite Ore	Nickel Pig Iron (NPI)	Steel intermediate	Stainless Steel	PYROMETALLURGY
	Ferronickel (FeNi)	Ni Powder	Nickel alloy	
	High Ni Matte	Electrolytic Nickel	Plating	
	Low Ni Matte	Ni Briquette	Baterai EV	
Limonite Ore	Mixed Hydroxide Precipitate (MHP)	Nickel Sulphate	Baterai EV	HYDROMETALLURGY
1X	3-10X	15-30X	30-67X	Price (ratio to ore)

Source: WRI Indonesia analysis

Based on calculations of energy use and GHG emissions in Indonesia's nickel mining and primary extraction sub-sector, total GHG emissions in 2023 amounted to 170.2 million tons of CO_2e. This figure represents 21% of national emissions from the energy and IPPU sectors. Of this total, pyrometallurgical smelters contributed the largest share of emissions—166.6 million tons of CO_2e, or approximately 98%. This is primarily due to the high production volume and the emission-intensive characteristics of the RKEF smelting process.

Figure 19.
GHG emissions by sub-sector in the nickel industry, 2023

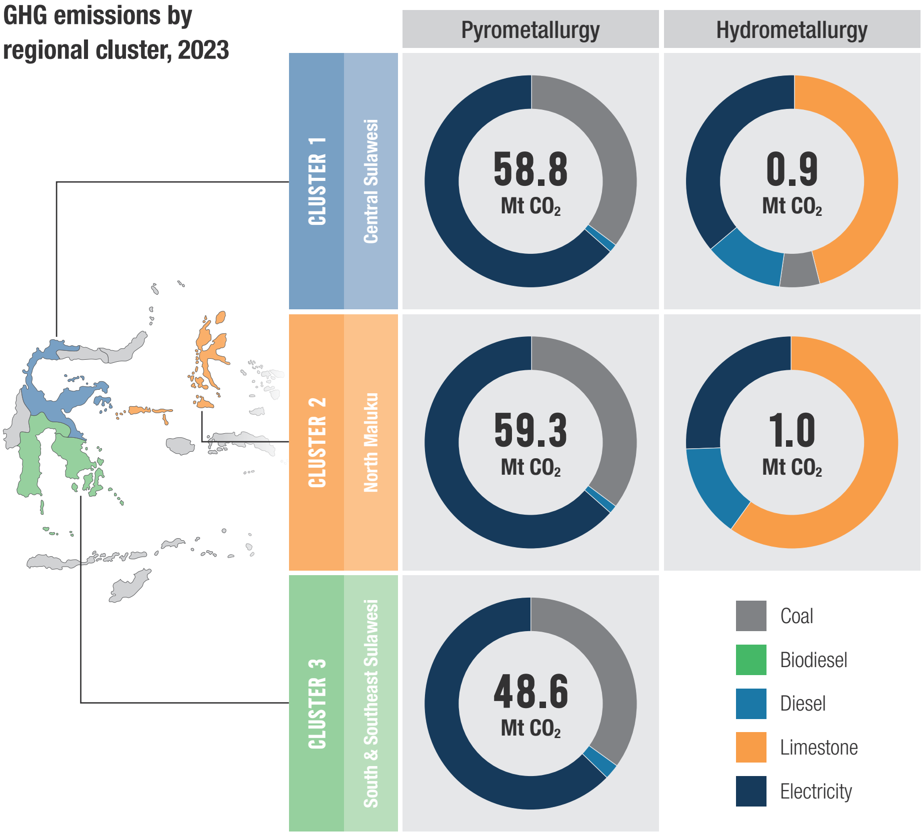


** Mining emissions only account for energy use*

Source: WRI Indonesia analysis

Based on this emissions profile, the roadmap estimates the volume of emissions produced by each regional cluster in 2023. The results show that Clusters 1 and 2 were the highest emitters due to their large nickel smelting capacity. In contrast, Cluster 3 recorded relatively lower emissions, driven by a smaller number of smelters and the presence of smelters powered by hydroelectric plants (HPP). The composition of emission sources is generally similar across all clusters, dominated by direct coal use and electricity generated by CFPP. This similarity is due to the consistent use of technologies and fuel types across the regions.

Figure 20.
Nickel industry GHG emissions by regional cluster, 2023

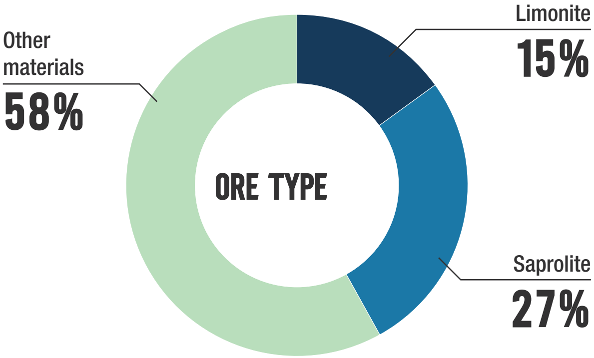


2.1

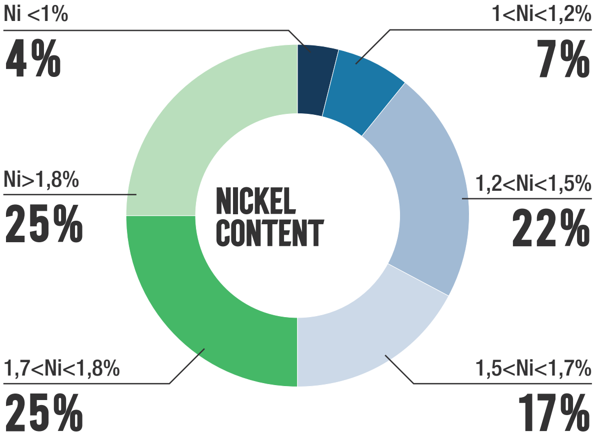
BASELINE CONDITIONS OF THE MINING SUB-SECTOR

Figure 21.
National nickel reserves by ore type and nickel content

Nickel reserves by laterite ore type
(100% = 5.3 billion WMT or 56.1 million ton Ni-eq)



Nickel reserves by content
(100% = 5.3 billion WMT or 56.1 million ton Ni-eq)



Source: Ministry of Energy and Mineral Resources (2024)

Globally, nickel ore is divided into two main types: sulphide ore, commonly found in subtropical regions, and laterite (oxide) ore, which is abundant in equatorial areas. Laterite reserves are estimated to be larger than sulphide reserves.

In Indonesia, all nickel ore is of the laterite type, formed through the weathering of ultramafic rocks such as olivine and pyroxene. This weathering process occurs only in specific areas, including East and South Kalimantan, Central and Southeast Sulawesi, Seram Island, Obi Island, East Halmahera, Gag Island, Waigeo Island, and northern Papua. According to data from the Ministry of Energy and Mineral Resources (ESDM, 2023), the largest nickel metal reserves are located in Southeast Sulawesi, North Maluku, and Central Sulawesi.

In 2023, Indonesia was estimated to have total nickel metal resources and reserves of 184.6 million tons and 56.1 million tons, respectively (ESDM, 2024). These reserves account for 42.3% of global reserves in 2023 (USGS, 2024). Indonesia’s nickel reserves are found in various types of ore, including saprolite, limonite, and other materials. Saprolite and limonite each represent 22% and 16% of the national reserves, while the remaining 62% are contained in other materials such as overburden, bedrock, and others (ESDM, 2024).

Each type of ore generally has different nickel content. Most limonite nickel ore has a nickel content below 1.2%, although a small portion can reach up to 1.7%. In contrast, most saprolite and other materials contain nickel levels above 1.2%, and some exceed 1.7%. In total, two-thirds of Indonesia’s nickel ore reserves have a nickel content above 1.5%, which is considered relatively high. The remaining 33% comprises lower-grade reserves.

2.1.1

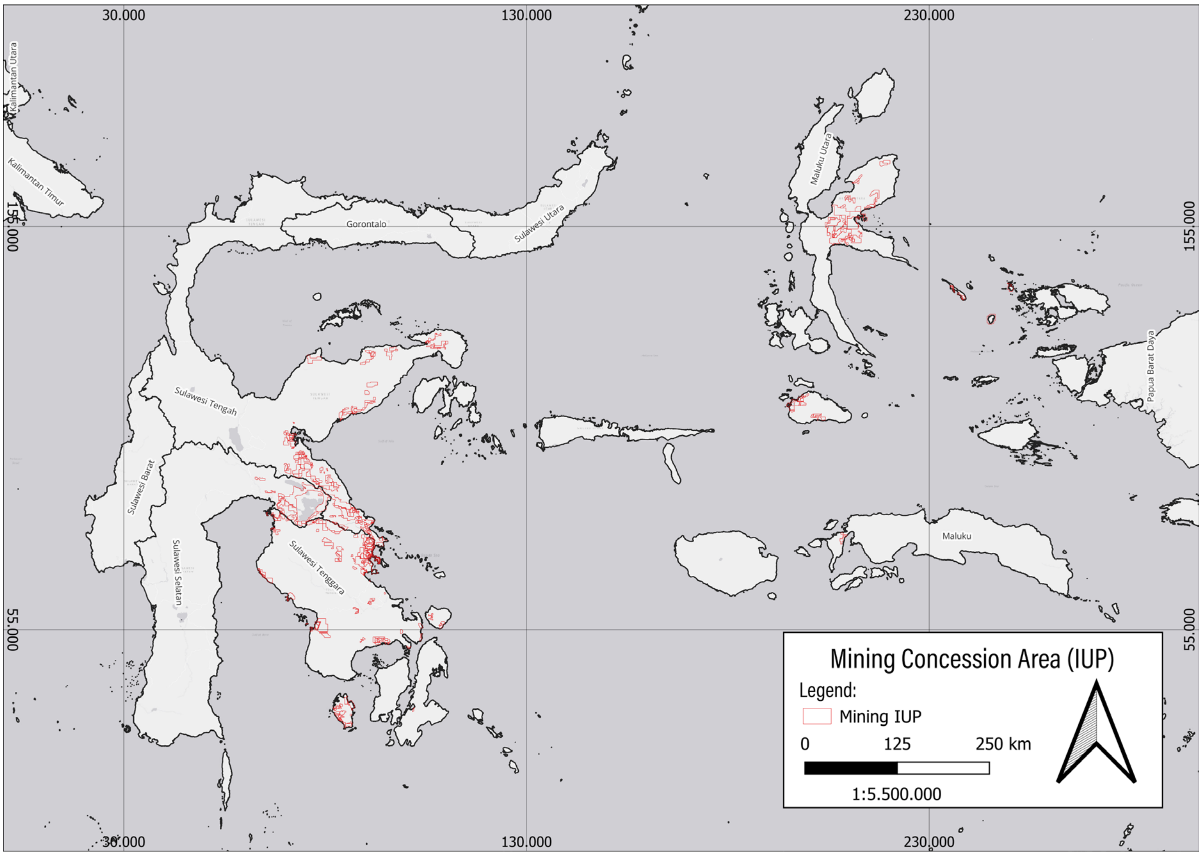
DISTRIBUTION OF NICKEL MINING AND PRODUCTION CAPACITY

By 2024, there will be a total of 386 active nickel mining permits, including Mining Business Permits (IUP), Special Mining Business Permits (IUP-K) and Contracts of Work (CoW). with a total permit area of 987,784 hectares. The total area of nickel mine production operation permits is 950,462 hectares spread across Central Sulawesi (38.0%), Southeast Sulawesi (28.7%), North Maluku (23.0%), South Sulawesi (4.2%), West Papua (1.9%), and Maluku (0.4%).

Table 1.
Profile of the nickel mining industry in the five main nickel-producing provinces in 2024

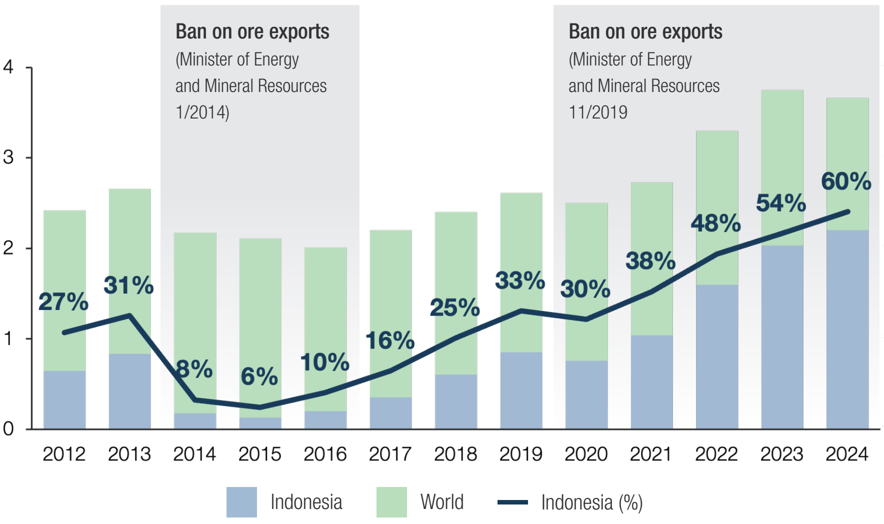
Province	Reserves (billion WMT)	RKAB (million WMT)	Permits (production operation stage)			
			IUP	IUPK	KK	Total area (thousand Ha)
Southeast Sulawesi	1.7	92.9	172	2	-	272.8
Sulawesi Tengah	0.8	42.7	130	1	-	361.2
West Papua	0.1	4.3	1	-	1	180.6
North Maluku	1.9	63.4	55	-	1	218.6
Sulawesi Selatan	0.6	17.7	11			39.9

Figure 22.
Distribution of nickel mining area



In general, nickel mining production in Indonesia has experienced a significant increase from year to year. Compared to 2012, nickel ore production more than tripled by 2024. As a result, Indonesia's contribution to global nickel ore supply also rose, from 27% to 60% over the same period. This trend has been primarily driven by demand from the domestic primary extraction or smelting industry. Since 2014, the government has attempted to implement an export ban on nickel ore to stimulate the development of domestic processing industries. However, the results of implementing Minister of Energy and Mineral Resources Regulation No. 1/2014 on Value Addition were suboptimal and instead led to a decline in mining production. It was only in 2020 that the nickel ore export ban yielded positive results through the implementation of Minister of Energy and Mineral Resources Regulation No. 11/2019. The effectiveness of this regulation was supported by the operation of smelters built between 2012 and 2019, followed by the construction of many additional smelters.

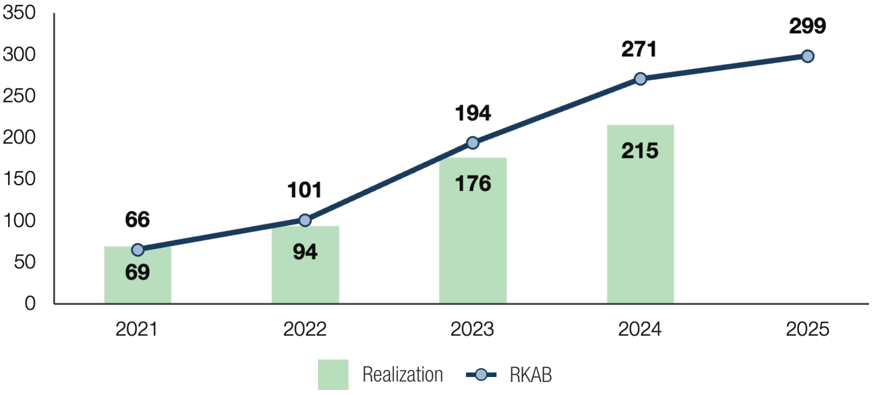
Figure 23.
Indonesia's nickel ore production
Million Ni-equivalent



Source: USGS (2016), USGS (2019), USGS (2023), USGS (2025)

In addition to being influenced by market demand, nickel ore production is also regulated through mining quotas in the form of the Work Plan and Budget (RKAB), which must be approved by the Minister of Energy and Mineral Resources. Through the RKAB instrument, the government aims to align mining production volumes with smelter demand, preventing oversupply and misuse in nickel ore sales. Since 2021, the government has continued to increase nickel ore mining quotas in line with the expansion of the smelting industry. Despite concerns over oversupply that have contributed to a global drop in nickel prices, the government has decided to further raise the RKAB quota in 2025. Therefore, a decline in nickel ore production in the near future is considered unlikely.

Figure 24.
RKAB and the realization of national nickel ore mining
Wet metric tons (WMT)



Source: APNI (2025); Geological Survey (2024); Director General of Mineral and Mineral Resources (2025)

2.1.2

ENERGY AND EMISSIONS PROFILE

In general, the stages of laterite nickel ore mining activities include, land clearing, overburden dredging, ore mining, ore transportation (hauling), ore shipment (barging), and mine closure.

Figure 25.
Stages of laterite nickel ore mining activities

Land preparation for mining involves the systematic stripping and removal of surface vegetation to prepare the area for subsequent extraction activities. This process is followed by stripping the top soil about one meter deep which contains a lot of organic material. The two initial processes were carried out using heavy equipment, such as excavators, bulldozers, and dump trucks.

After the topsoil layer is removed, overburden excavation and removal are carried out. In this stage, excavators are used to dig out materials that have no economic value, in order to facilitate the mining process and prevent contamination with the ore.

Nickel ore mining operations include excavation, transportation to the stockpile area, and shipping (barging) to barges. The selective mining process (ore getting) is carried out using excavators, with a separation between ore material and non-ore (waste) material. The ore is transported to the stockpile area, while waste material is disposed of in the out-pit dump. At the stockpile site, ores are typically blended to achieve specific characteristics/specifications. Afterwards, the ore is transported to a dedicated terminal (jetty) to be loaded onto barges and shipped to the intended destination.

However, in some cases, nickel ore is transported directly to the smelter using dump trucks. The choice of transport mode depends on the location of the mine and the smelter purchasing the ore.

After the mine's operational period ends, the mining company is responsible for restoring the land to its original condition or to an improved state. This mine closure process includes dismantling infrastructure, closing the pit, reclaiming and revegetating overburden dumps and backfilling areas, and conducting post-mining monitoring.

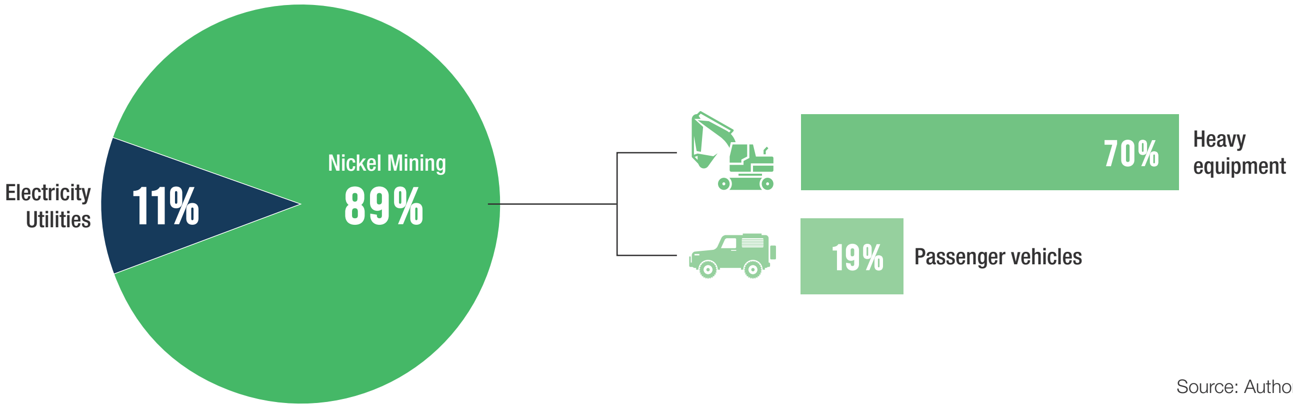
Based on this typical sequence of nickel mining activities, GHG emissions are produced from the use of heavy machinery and operational vehicles (categorized as mobile combustion) as well as electricity consumption for office and utility needs (categorized as stationary combustion). For the purpose of this study, emissions from land clearing activities are not included in the calculations.

In this roadmap, the year 2023 is used as the baseline. Based on data from four nickel mining companies sampled, the average GHG emissions intensity is 14.9 kg CO_2e per dry metric ton (DMT) of nickel ore mined. This figure is equivalent to 874 kg CO_2e per ton of nickel, based on the average reported nickel content (grade) from the companies.

Mining activities—particularly the use of heavy machinery and operational vehicles—account for 89% of total emissions from the mining sub-sector. The remaining 11% comes from supporting components, primarily electricity generation using diesel-powered generators.

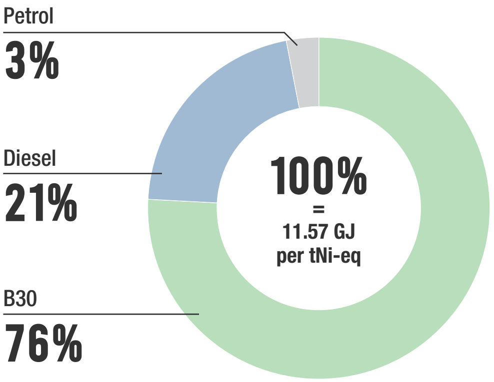
Within nickel mining operations, the majority of GHG emissions originate from the use of heavy machinery. At least 70% of total mining emissions are attributed to heavy equipment used throughout the various stages of mining. Additionally, 19% of emissions are generated from passenger vehicles used for monitoring and other mobility-related activities. Thus, the use of heavy machinery is identified as the primary emission hotspot in nickel mining.

Figure 26.
GHG emission profile of nickel mining sub-sector
%



Source: Author

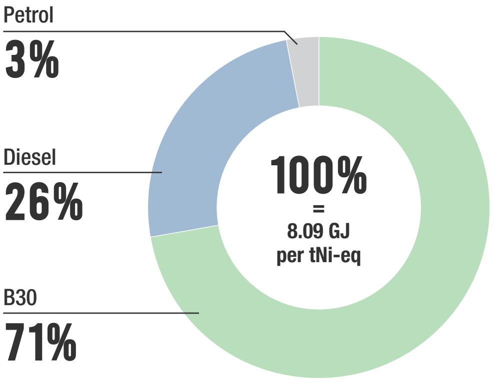
Figure 27.
Energy mix in nickel mining
%



Source: Author

From the energy perspective, B30 biodiesel is the primary energy source in the nickel mining sub-sector. B30 contributes 76% of the total energy mix. In contrast, the smallest share in the energy mix comes from electricity purchased from third parties. This is due to the intensive use of heavy equipment throughout all stages, from land preparation to mine reclamation. At the same time, the use of purchased electricity is very low because mining sites are typically isolated and not connected to the transmission grid. Generally, miners generate their own electricity using diesel-powered generators.

Figure 28.
Energy mix on machines
%



Source: Author

In heavy equipment operations, B30 contributes 71% of the energy mix, followed by diesel fuel at 26%. Thus, these two diesel-based fuels account for 97% of the energy used by heavy machinery. This indicates that diesel fuel use in heavy equipment is the primary source of emissions in nickel mining. Therefore, reducing diesel fuel consumption can be an effective measure to lower emissions. This can be achieved by increasing the proportion of pure biodiesel blend (FAME) and electrifying heavy equipment.

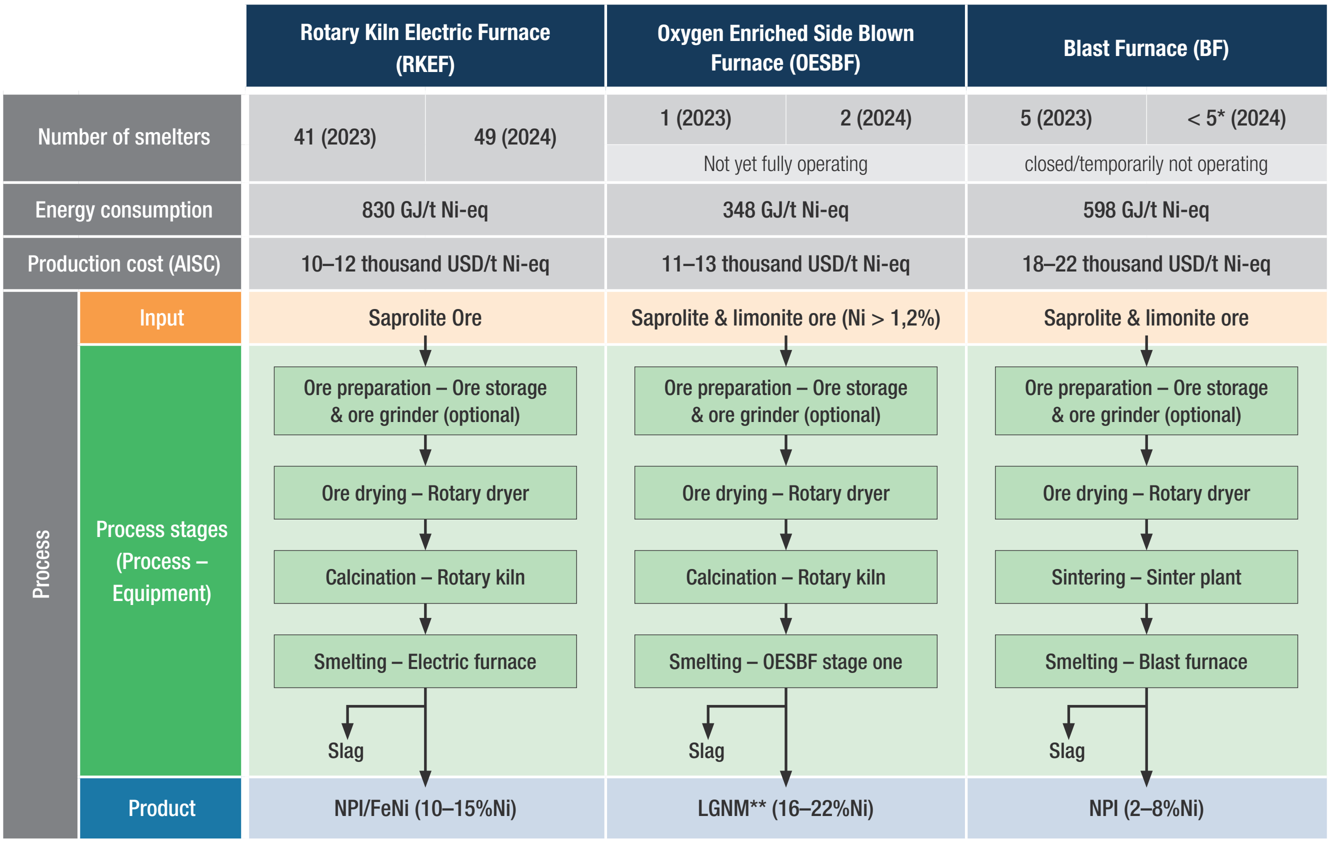
2.2

BASELINE CONDITIONS OF THE PYRO-METALLURGICAL SUB-SECTOR

As of 2024, the majority of nickel ore in Indonesia is still processed into intermediate products, which are then exported. In the pyrometallurgical production process, the input used is saprolite-type laterite ore, with outputs including NPI (Nickel Pig Iron), FeNi (ferronickel), and nickel matte. There are three types of pyrometallurgical processing technologies: Rotary Kiln Electric Furnace (RKEF), Oxygen Enriched Side Blown Furnace (OESBF), and Blast Furnace (BF). RKEF technology, used by almost all pyrometallurgical smelters in Indonesia, processes saprolite ore into NPI or FeNi. In contrast, BF is an older technology for producing NPI that has been largely abandoned due to its high operating costs. Unlike RKEF and BF, the OESBF technology produces nickel matte as its output. RKEF smelters can also produce nickel matte by further processing NPI using a converter.

This roadmap focuses on RKEF smelters, which account for 90% of the pyrometallurgical nickel processing industry. RKEF's dominance is expected to continue due to significant additions of new smelters in 2024. Conversely, older BF smelters are being partially or fully shut down because their high production costs are no longer competitive. Meanwhile, OESBF smelters are growing slowly due to the immaturity of the technology and the more limited market for nickel matte.

Figure 29.
Production routes at pyrometallurgical nickel smelters in Indonesia



		Rotary Kiln Electric Furnace (RKEF)	Oxygen Enriched Side Blown Furnace (OESBF)	Blast Furnace (BF)
Number of smelters		41 (2023) 49 (2024)	1 (2023) 2 (2024) Not yet fully operating	5 (2023) < 5* (2024) closed/temporarily not operating
Energy consumption		830 GJ/t Ni-eq	348 GJ/t Ni-eq	598 GJ/t Ni-eq
Production cost (AISC)		10–12 thousand USD/t Ni-eq	11–13 thousand USD/t Ni-eq	18–22 thousand USD/t Ni-eq
Process	Input	Saprolite Ore	Saprolite & limonite ore (Ni > 1,2%)	Saprolite & limonite ore
	Process stages (Process – Equipment)	Ore preparation – Ore storage & ore grinder (optional) Ore drying – Rotary dryer Calcination – Rotary kiln Smelting – Electric furnace Slag	Ore preparation – Ore storage & ore grinder (optional) Ore drying – Rotary dryer Calcination – Rotary kiln Smelting – OESBF stage one Slag	Ore preparation – Ore storage & ore grinder (optional) Ore drying – Rotary dryer Sintering – Sinter plant Smelting – Blast furnace Slag
	Product	NPI/FeNi (10–15%Ni)	LGNM** (16–22%Ni)	NPI (2–8%Ni)

** Some have closed or are temporarily not operating*
*** Low-grade nickel matte*

Source: Author

2.2.1

SMELTER DISTRIBUTION AND PRODUCTION CAPACITY

This roadmap uses national nickel production figures from the pyrometallurgical route, amounting to 1,794 thousand tons of Ni-eq in 2023, contained in various intermediate products such as NPI, FeNi, and nickel matte. Considering that many BF smelters have shut down and OESBF smelters are not yet operating stably, the entire national production is attributed to RKEF smelters.

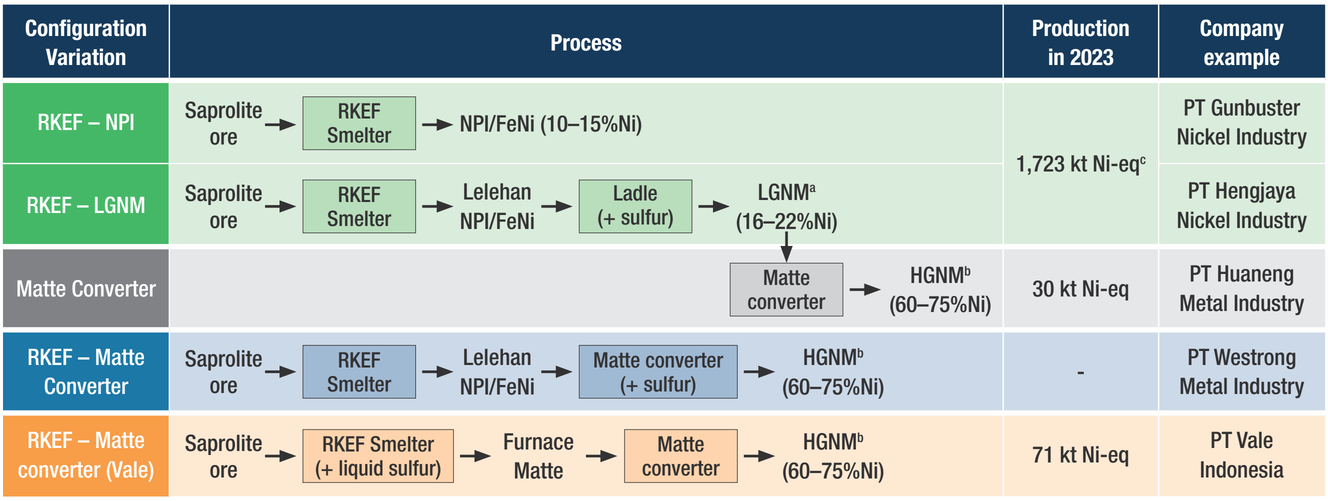
In practice, RKEF smelters vary in process configuration, which determines the type of nickel product produced. Typically, RKEF smelters produce NPI or FeNi. However, some RKEF smelters add a sulphur injection and air-blowing process to the molten NPI/FeNi, producing Low-grade Nickel Matte (LGNM). For instance, in the Indonesia Morowali Industrial Park (IMIP), at least 20 RKEF production lines can produce LGNM (MMTA, 2024).

Some other RKEF smelters can produce products with higher purity, namely in the form of High-grade Nickel Matte (HGNM). HGNM is produced through a matte conversion process in a Pierce-Smith Converter or Bottom-blown Converter. In Indonesia, there are converters that are stand alone and integrated with RKEF smelters. The stand-alone type buys LGNM from other RKEF smelters as raw materials for HGNM production. Meanwhile, the integrated type is capable of producing HGNM from crude nickel ore.

RKEF smelters integrated with matte converters have two forms of process configuration. The first form is a typical RKEF – Matte Converter smelter that uses Chinese technology, while the second form is a smelter owned by PT Vale Indonesia in Sorowako, South Sulawesi. The difference between the two lies in the sulphur delivery mechanism to separate nickel from iron content and other impurities. The process in the RKEF – Matte Converter smelter is a combination of the LGNM production process with a matte converter to produce HGNM. In this process, the RKEF smelter produces NPI/FeNi melt which is then blown with air and sulphur. Meanwhile, the Vale Sorowako smelter added liquid sulphur to the calcination process at the rotary kiln. Thus, the smelting in the electric furnace does not produce NPI/FeNi but a matte furnace which is then further processed into HGNM.

According to 2023 data, nearly all pyrometallurgical smelters in Indonesia produced NPI, FeNi, and LGNM with a total volume of 1,723 kt Ni-eq. Of this amount, approximately 264 kt of NPI and FeNi were further processed by domestic stainless steel plants, while the remainder was exported. For LGNM, around 33 kt were further refined into 30 kt of HGNM through stand-alone matte converters. In addition, there was HGNM production amounting to 71 kt Ni-eq, processed from nickel ore within an integrated smelter facility owned by PT Vale Indonesia. Several other smelters are known to produce HGNM directly from ore as well, but they only began operating in 2024 and are therefore not included in the dataset used in this roadmap.

Figure 30.
Typical configuration of RKEF smelters

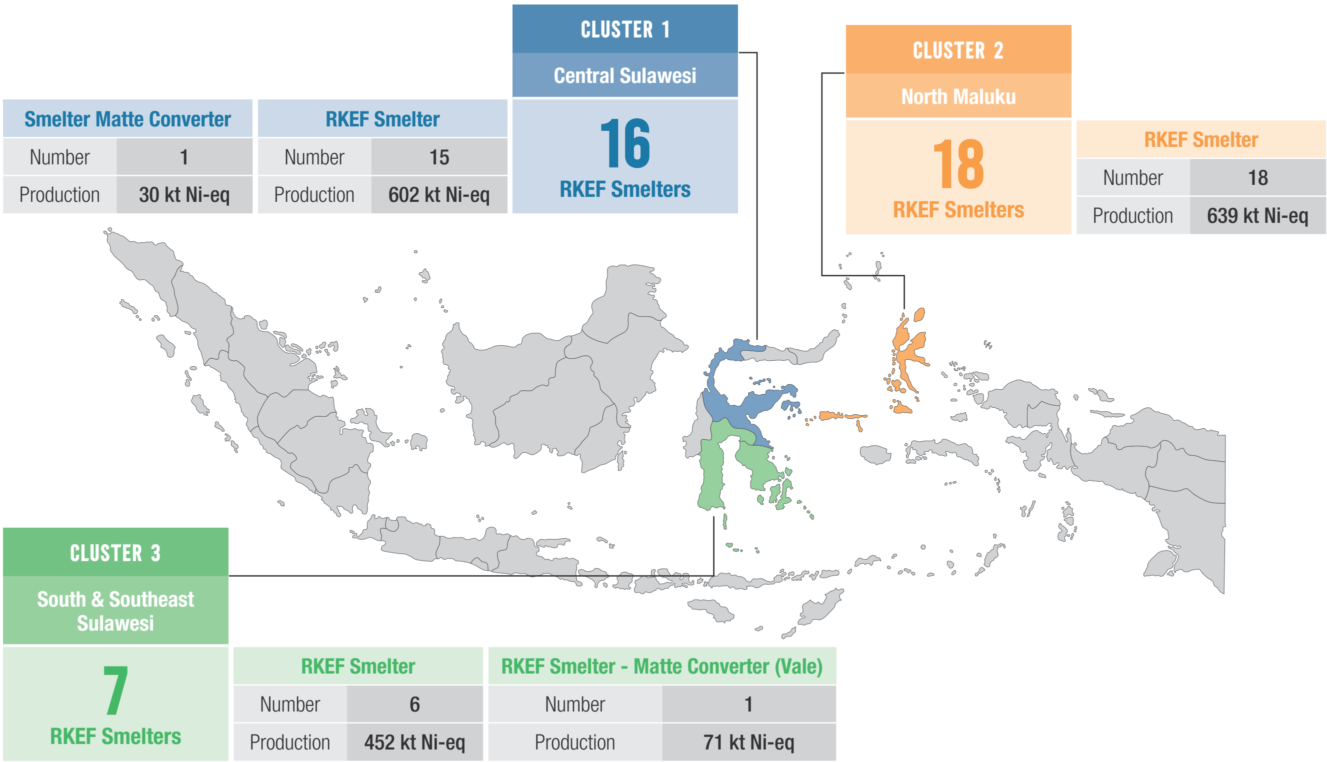


Configuration Variation	Process	Production in 2023	Company example
RKEF – NPI	Saprolite ore → RKEF Smelter → NPI/FeNi (10–15%Ni)	1,723 kt Ni-eq[c]	PT Gunbuster Nickel Industry
RKEF – LGNM	Saprolite ore → RKEF Smelter → Lelehan NPI/FeNi → Ladle (+ sulfur) → LGNM[a] (16–22%Ni) ↓		PT Hengjaya Nickel Industry
Matte Converter	Matte converter → HGNM[b] (60–75%Ni)	30 kt Ni-eq	PT Huaneng Metal Industry
RKEF – Matte Converter	Saprolite ore → RKEF Smelter → Lelehan NPI/FeNi → Matte converter (+ sulfur) → HGNM[b] (60–75%Ni)	-	PT Westrong Metal Industry
RKEF – Matte converter (Vale)	Saprolite ore → RKEF Smelter (+ liquid sulfur) → Furnace Matte → Matte converter → HGNM[b] (60–75%Ni)	71 kt Ni-eq	PT Vale Indonesia

[a] LGNM (Low-grade nickel matte)
[b] HGNM (High-grade nickel matte)
[c] Tidak tersedia data resmi produksi LGNM karena perusahaan yang sama dapat memproduksi NPI/ FeNi

In 2023, RKEF smelters were only located in the provinces of Central Sulawesi, South Sulawesi, Southeast Sulawesi, and North Maluku. Based on the regional cluster division in this roadmap, Cluster 2 (North Maluku) was the area with the highest number of smelters and the largest production output. This is largely due to the presence of two major nickel industrial zones: the Indonesia Weda Bay Industrial Park (IWIP) and the Obi Island Industrial Zone. Meanwhile, Clusters 1 and 3 each had only one major industrial zone in operation.

Figure 31.
Number of RKEF smelters by region in 2023



CLUSTER 1
Central Sulawesi
16
RKEF Smelters

Smelter Matte Converter	
Number	1
Production	30 kt Ni-eq

RKEF Smelter	
Number	15
Production	602 kt Ni-eq

CLUSTER 2
North Maluku
18
RKEF Smelters

RKEF Smelter	
Number	18
Production	639 kt Ni-eq

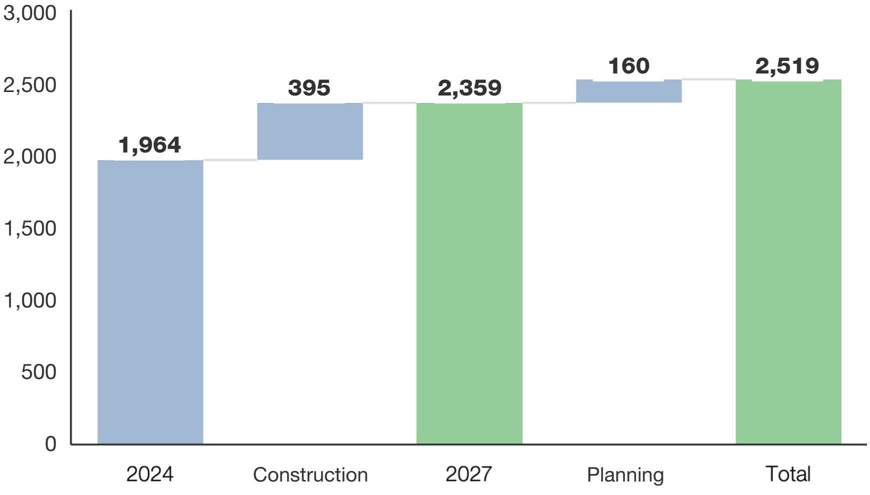
CLUSTER 3
South & Southeast Sulawesi
7
RKEF Smelters

RKEF Smelter	
Number	6
Production	452 kt Ni-eq

RKEF Smelter - Matte Converter (Vale)	
Number	1
Production	71 kt Ni-eq

According to data from the Coordinating Ministry for Maritime Affairs and Investment, production of pyrometallurgical nickel has increased to 1,964 kt-Ni in 2024. Additionally, several smelters are currently under construction, with an added production capacity of up to 395 kt-Ni, while other smelters are in the planning phase, with an additional projected capacity of 160 kt-Ni. Based on these development plans, the production capacity of nickel through the pyrometallurgical route is expected to continue growing, reaching 2,519 kt-Ni by 2030. For the purposes of this study, it is assumed that there will be no further growth in production capacity beyond 2030 until the end of 2050.

Figure 32.
Pyrometallurgical nickel production by project in pipeline
Ton Ni-eq



Source: Coordinating Ministry for Maritime and Investment Affairs (2024)

2.2.2

ENERGY AND EMISSIONS PROFILE

In general, the processing of laterite nickel ore via the pyrometallurgical process consists of five main sequential stages: ore preparation, drying, calcination, reduction, and refining.

Ore preparation

Ore preparation is carried out to ensure the availability of ore with the desired quality as input. Laterite ore is transported using heavy vehicles to a stockpile area, where it is crushed and separated from waste before being sent to the processing facility.

In this activity, the primary energy demand comes from the operation of mobile equipment. Based on collected activity data, around 9.03 TJ per ton of nickel (Ni) is required for ore transportation, preparation, and storage prior to drying in a rotary dryer. Nearly all of this energy comes from diesel fuel (98.9%), with the remaining 1.1% from biodiesel types B30 and B35. The high diesel usage contributes to GHG emissions of approximately 0.74 tCO_2e per ton of nickel.

Ore drying

In general, mined nickel ore contains varying moisture levels depending on whether extraction took place during the wet or dry season. Drying is essential to ensure consistent moisture content in the calcination and reduction processes, with a target of around 20% moisture. This helps prevent ore from sticking to equipment and limits excessive dust formation in exhaust gases.

The evaporation of moisture from laterite ore is an endothermic process that requires a heat input. This drying process is carried out by feeding the laterite ore into a rotating furnace (rotary dryer). Simultaneously, hot vapour produced from the combustion of coal, diesel, or natural gas is channelled into the furnace to reduce the ore's moisture content at a temperature of approximately 800°C. The average energy intensity required for the drying process is 98.6 TJ per ton of nickel.

At the national aggregate level, sub-bituminous coal accounts for 98.3% of the energy mix for the drying process, followed by diesel (1.3%) and biodiesel (0.4%). Coal is primarily used by newer-generation RKEF smelters, while diesel, in the form of Marine Fuel Oil (MFO), is typically used by older-generation smelters in Indonesia. In addition, Industrial Diesel Oil (IDO) is also used, albeit in small amounts, by both old and new smelters. The use of diesel is gradually being replaced by biodiesel. Due to the heavy use of coal in the rotary dryer process, the average GHG emissions produced during the drying stage reach 9.9 tons of CO_2 equivalent (tCO_2e) per ton of nickel.

Calcination

The dried ore is then further processed in a rotary kiln for calcination and partial reduction. A rotary kiln is a rotating cylindrical furnace tilted at approximately 4° horizontally, with a counter-current combustion system. In this system, the nickel ore is fed from the top and comes into contact with the heat generated by fuel combustion at the lower end of the kiln. In some cases, the dry ore is pre-mixed with reductants such as anthracite or semi-coke before being fed into the kiln; in others, the reductant is added simultaneously with the fuel.
This process operates at a system temperature of around 850–1000°C.

Under these conditions, any remaining moisture in the nickel ore is removed to prevent explosions in the electric furnace downstream. At the same time, the carbon content in the reductant reduces about 20–25% of nickel oxide (NiO) to metallic nickel (Ni) and ferric oxide (Fe_2O_3) to FeO and a small amount of Fe (Zulhan, 2024). The primary output of this stage is calcine, while the by-products include ash and exhaust gas.

Based on collected operational data, the average energy intensity for calcination in rotary kilns is 132.7 TJ per ton of nickel. Nationally, the energy mix for this process is dominated by coal (95.9%), followed by diesel (4.1%) and biodiesel (0.02%). As a reductant, companies also use anthracite or semi-coke at a rate of 3.7 tons per ton of nickel. This process generates 23.1 tons of CO_2 equivalent (tCO_2e) per ton of nickel, broken down into 13.2 tCO_2e per ton of nickel from fuel combustion and 9.9 tCO_2e per ton of nickel from reductant use. In some cases, limestone is added to the rotary kiln to prevent material build-up and corrosion on the refractory walls of the kiln and furnace. When this occurs, an additional 0.2 tCO_2e per ton of nickel is emitted from limestone decomposition.

Smelting

The next stage is smelting in an electric furnace. In this phase, the calcine is heated to a temperature of around 1600°C to reduce approximately 75–80% of the remaining nickel oxide into metallic nickel and about 95% of the remaining iron oxide into iron. This process results in the formation of a nickel-iron alloy in the form of ferronickel (FeNi) or nickel pig iron (NPI), with nickel content in the product ranging between 10–15%.

The heat used in the smelting process comes from electricity, delivered through carbon-based electrodes (graphite).

On average, this stage requires 500.6 terajoules (TJ) per ton of nickel in the form of primary energy input at power plants to supply electricity to the electric furnace. In Indonesia, nearly all RKEF smelters use electricity generated from captive power plants operated by the smelters or industrial zones themselves. Almost all of these captive power plants are CFPP, making coal responsible for 98.6% of the primary energy mix in RKEF smelter power generation nationally. A small portion of the energy mix comes from renewables (0.8%), specifically three hydropower plants (HPP) owned by PT Vale Indonesia with a combined installed capacity of 365 MW, and diesel (0.5%), which is used in diesel power plants (DPP) or as backup energy in coal plants. Based on this energy profile, the emissions intensity from the electric furnace stage is calculated at 50.3 tons of CO_2 equivalent (tCO_2e) per ton of nickel.

As shown in **Figure 30**, there are three processing routes following the smelting stage in the electric furnace:

- **The first route** is for smelters that produce NPI (Nickel Pig Iron) or FeNi (ferronickel). The molten NPI/FeNi from the furnace can either be directly transported to nearby stainless steel plants or cast into alloy blocks for export.
- **The second route** is for smelters that produce Low-Grade Nickel Matte (LGNM). In this process, the molten NPI/FeNi is blown with air and sulphur as it exits the furnace (tapping out), which helps reduce the iron content and forms nickel matte. The LGNM can either be exported directly or further refined domestically into High-Grade Nickel Matte (HGNM).
- **The third route** represents a smelter owned by PT Vale Indonesia which produces intermediate products in the form of matte furnaces. This product is formed as a result of the addition of liquid sulphur at the calcination stage. The furnace matte is further processed into HGNM.

Matte conversion

The conversion stage is carried out using a matte converter and is aimed at refining LGNM (Low-Grade Nickel Matte), which contains 16–22% nickel, or furnace matte into HGNM (High-Grade Nickel Matte), which contains 60–75% nickel. Out of the total 1,794 kilotons of nickel contained in NPI, FeNi, LGNM, and furnace matte, only 101 kilotons of nickel end up as HGNM. At this stage, the LGNM melt or furnace matte is poured into the converter furnace and mixed with silica. Then, air is fired into the furnace through the tuyere. The air will trigger the oxidation of iron and sulphur content in the LGNM and furnace matte. Next, the silica will form slag with oxidized iron, so that the nickel becomes more and more pure. The slag from the converter is reutilized in the conversion process to stabilize the process.

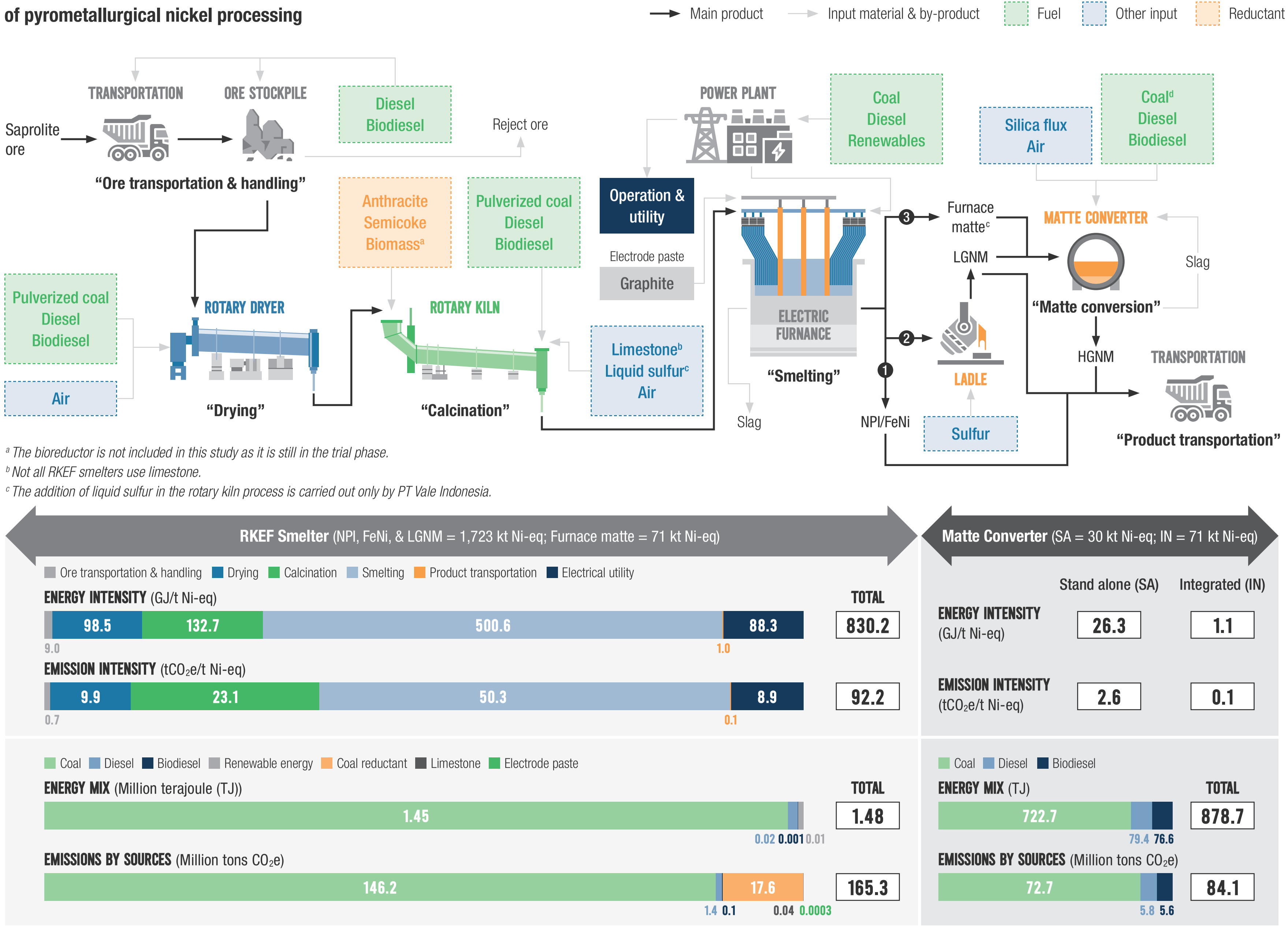
For matte converters that operate separately from the RKEF smelter, the energy requirement reaches 26.3 GJ per ton of nickel with emissions of 2.6 tCO_2e per ton of nickel. The majority of energy consumption and emissions come from burning coal in power plants and biodiesel in heavy equipment. Meanwhile, the converter integrated with the RKEF smelter only requires 1.1 GJ/ton of Ni and produces 0.1 tCO_2e per ton of nickel. The integration of the converter with the RKEF smelter, allows the use of heavy equipment and fuel for less furnace heating.

Electrical utilities

In addition to energy requirements for the main processing stages, there are other energy needs for utility operations, including office functions and machine operation within the plant, which are powered by electricity. These activities consume approximately 15% of the total electricity supplied, equivalent to 88.3 TJ per ton of nickel in the form of primary energy. The energy mix is the same as that used in the power plants, which is dominated by coal (98.6%). As a result, the emission intensity for utility-related electricity use can reach 8.9 tCO_2e per ton of nickel.

On average, the processing of laterite nickel ore into HGNM through RKEF smelters and converters requires 831.3–856.5 TJ per ton of nickel and produces emissions of 92.9 tCO_2e per ton of nickel.

Figure 33.
Summary of the energy and emissions profile of pyrometallurgical nickel processing



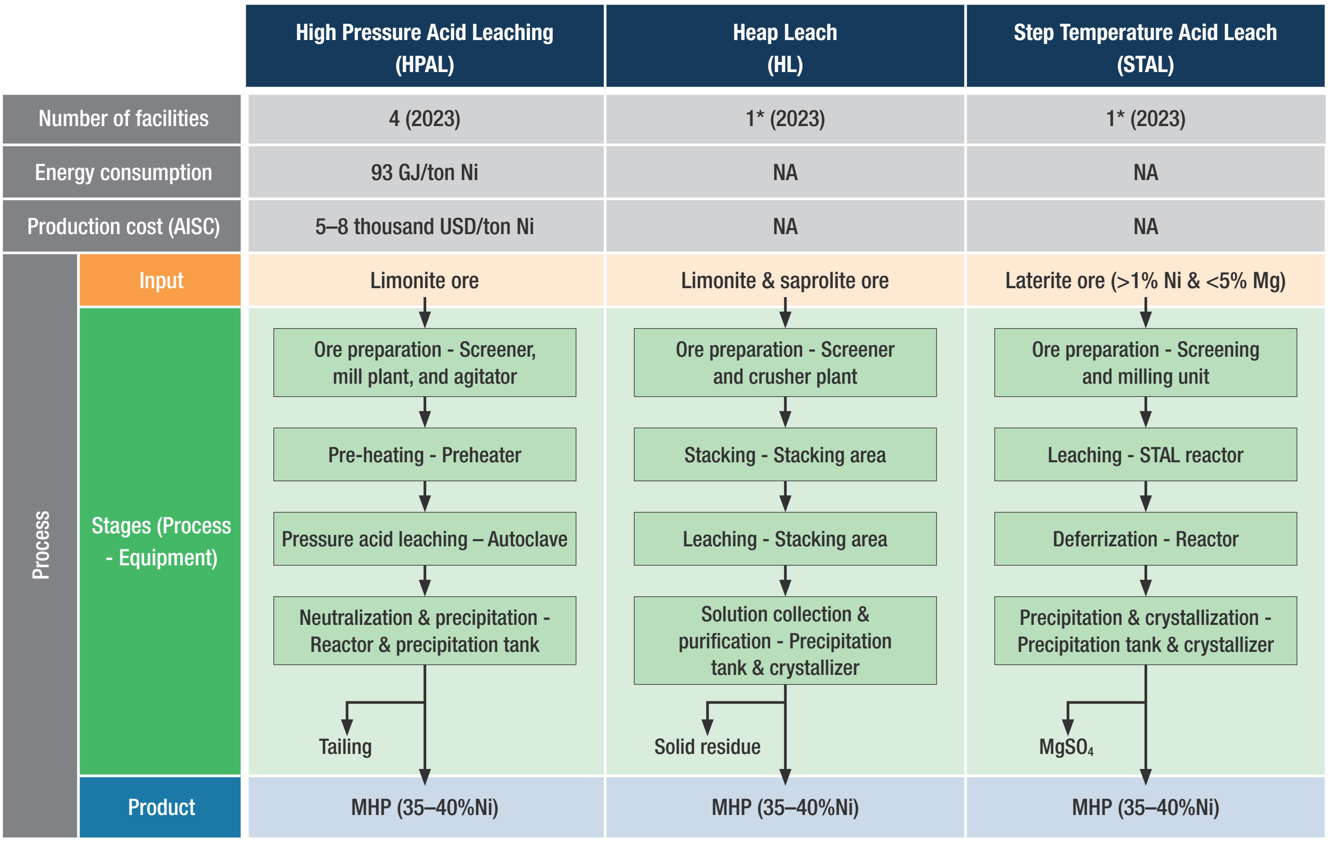
[a] The bioreductor is not included in this study as it is still in the trial phase.
[b] Not all RKEF smelters use limestone.
[c] The addition of liquid sulfur in the rotary kiln process is carried out only by PT Vale Indonesia.

2.3

BASELINE CONDITIONS OF THE HYDRO-METALLURGICAL SUB-SECTOR

The pyrometallurgical processing route cannot treat laterite ore with high iron content, so it is limited to processing saprolite-type laterite ore. As a result, limonite-type laterite ore can currently only be processed through the hydrometallurgical route. In 2023, four hydrometallurgical nickel processing facilities were operational in Indonesia, all using High Pressure Acid Leaching (HPAL) technology. As the name suggests, this process separates nickel and cobalt metals by leaching them with acid under high-pressure system conditions. Additionally, there are two other hydrometallurgical facilities under development, each using Heap Leach (HL) and Step Temperature Acid Leach (STAL) technologies.

Figure 34.
Hydrometallurgical production routes in Indonesia



		High Pressure Acid Leaching (HPAL)	Heap Leach (HL)	Step Temperature Acid Leach (STAL)
Number of facilities		4 (2023)	1* (2023)	1* (2023)
Energy consumption		93 GJ/ton Ni	NA	NA
Production cost (AISC)		5–8 thousand USD/ton Ni	NA	NA
Process	Input	Limonite ore	Limonite & saprolite ore	Laterite ore (>1% Ni & <5% Mg)
	Stages (Process - Equipment)	Ore preparation - Screener, mill plant, and agitator	Ore preparation - Screener and crusher plant	Ore preparation - Screening and milling unit
		Pre-heating - Preheater	Stacking - Stacking area	Leaching - STAL reactor
		Pressure acid leaching – Autoclave	Leaching - Stacking area	Deferrization - Reactor
		Neutralization & precipitation - Reactor & precipitation tank	Solution collection & purification - Precipitation tank & crystallizer	Precipitation & crystallization - Precipitation tank & crystallizer
		Tailing	Solid residue	$MgSO_4$
	Product	MHP (35–40%Ni)	MHP (35–40%Ni)	MHP (35–40%Ni)

** Still in piloting phase*

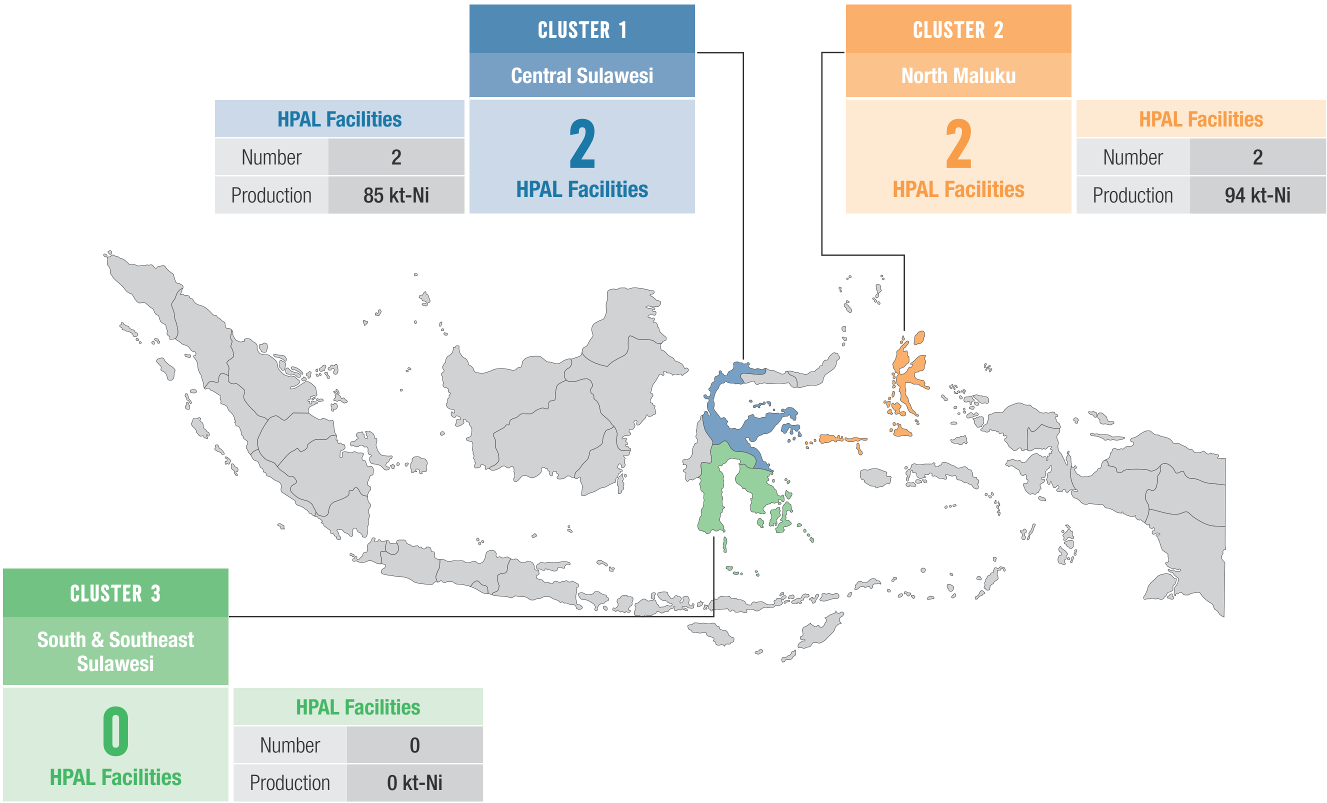
Source: Author

2.3.1

SMELTER DISTRIBUTION AND PRODUCTION CAPACITY

In 2023, the total nickel production from HPAL plants nationally is estimated at 179 kt-Ni in Mixed Hydroxide Precipitate (MHP) products. The location of the HPAL factory is evenly distributed in Clusters 1 and 2. Meanwhile, there are no HPAL facilities operating in Cluster 3 throughout 2023. The first HPAL plant in the region commenced operations in 2024.

Figure 35.
Number of HPAL facilities by region in 2023



CLUSTER 1
Central Sulawesi
2
HPAL Facilities

HPAL Facilities	
Number	2
Production	85 kt-Ni

CLUSTER 2
North Maluku
2
HPAL Facilities

HPAL Facilities	
Number	2
Production	94 kt-Ni

CLUSTER 3
South & Southeast Sulawesi
0
HPAL Facilities

HPAL Facilities	
Number	0
Production	0 kt-Ni

Based on data from the Coordinating Ministry for Maritime Affairs and Investment, the national MHP production capacity has reached 265 kt-Ni by 2024. Then, there are a number of facilities that are in the construction phase with an additional production capacity of 533 kt-Ni, as well as a smelter that is in the planning phase with an additional production capacity of 340 kt-Ni. Based on the development plan, it is estimated that the projected growth of nickel production capacity through hydrometallurgical production lines will still grow to 1,138 kt-Ni by 2030.

2.3.2

ENERGY AND EMISSIONS PROFILE

The main principle of the HPAL process is to dissolve nickel and cobalt with strong acids under high-pressure system conditions and high temperatures, thus separating them from ferrous metals and other impurities. To create the required system conditions, the HPAL process uses an autoclave as the main component in the polishing process.

Transport and preparation of ore

Before entering the leaching process, the limonite ore must be in a wet condition with a slurry-like consistency. To achieve this, the ore undergoes beneficiation through screening, grinding, and washing. The water content in the slurry is adjusted to approximately 62% before it enters the leaching process. This stage requires energy in the form of electricity to operate equipment and machinery, as well as fuel for transporting the ore to the HPAL plant. Transporting the nickel ore from the mine to the HPAL facility consumes 6.9 GJ per ton of nickel and results in emissions of 0.5 tCO_2e per ton of nickel.

Preheating, pressure acid leaching, and cooling

The leaching stage is carried out in an autoclave, a sealed reactor that operates at high temperature and pressure. Nickel ore containing metals such as nickel in the form of oxide (NiO) is treated with concentrated sulphuric acid. The purpose is to dissolve certain metals, including nickel, so they can be separated from other materials such as iron, which will precipitate.

To reduce the load on the autoclave during leaching, the slurry is typically preheated to around 190–205°C. The heated slurry then enters the autoclave, where it is leached using concentrated sulphuric acid under conditions of 240–270°C and pressures of 3,400–5,600 kPa. After exiting the autoclave, the slurry is rapidly cooled in a flash vessel. The steam generated from this cooling is then redirected back to the preheater.

This leaching stage in the autoclave is the most energy-intensive part of the process, primarily due to the large amount of steam required to heat and pressurize the system. Some HPAL facilities in Indonesia have integrated sulphuric acid plants that produce excess steam. This steam is used not only for leaching but also for electricity generation. In contrast, facilities without their own acid plants typically rely on coal-fired boilers to generate steam. These sulphuric acid plants convert raw sulphur into concentrated acid used in the leaching process. In some cases, companies still purchase sulphuric acid from third parties, either due to insufficient in-house quality or a lack of production facilities.

The average energy demand for the leaching process is 19.4 GJ per ton of nickel. Most of this energy (76.6%) is provided by waste heat from integrated sulphuric acid production. The remaining 23.4% comes from coal-fired boilers. Based on this energy profile, the emission intensity from the leaching process is 0.5 tCO_2e per ton of nickel, entirely attributed to coal combustion in the boilers.

Neutralization and precipitation

To separate iron (Fe) and aluminium (Al), dissolved limestone (in the form of slurry) is mixed with the leachate solution. Limestone acts as a neutralizing agent for the acid. During this process, air is also blown into the slurry to oxidize the iron. At the end of the neutralization stage, the pH is maintained between approximately 3.6 and 4.8 to hydrolyze Fe and Al, allowing them to precipitate. This condition also facilitates the separation of silicon dioxide. Once Fe and Al are separated, the resulting waste takes the form of sludge, which is then thickened and separated. The remaining product solution (overflow) continues to the next stage.

After iron (Fe) and aluminium (Al) are precipitated, the overflow from the previous process needs to be further treated to separate and precipitate the nickel and cobalt metals. The precipitation of these two metals can be carried out using nickel precipitation technology with caustic soda (NaOH) and quicklime (CaO) as reagents. This precipitation process is estimated to precipitate around 90% of nickel and cobalt ions in the form of hydroxides, which are then separated using a filter press. The filtered product can be directly sold as MHP (Mixed Hydroxide Precipitate) or further processed to produce nickel sulphate and cobalt sulphate.

Overall, the neutralization and precipitation processes do not require additional energy apart from electricity for machine operations. However, the use of limestone during the neutralization stage results in a reaction that releases CO_2. For the precipitation process, the addition of quicklime is required, which can be obtained either in its final form or through the calcination of limestone.

Based on the collected data, the average emission intensity for the neutralization and precipitation processes is estimated at 4.7 tCO_2e per ton of nickel. All of these emissions originate from the use of limestone consumed throughout the process.

Electrical utilities

In this study, the consumption of electrical energy from all stages of production (machinery) and office operational needs was calculated in aggregate. Considering that all HPAL facilities use electrical energy from captive coal-fired power plants, the energy and emissions are calculated based on the primary energy that is used to fuel coal-fired power plants. As a result, an average energy intensity of 32.8 GJ/t-Ni was obtained. Of the entire

energy use for electricity, it is found that 33.3% of electricity needs are met from the reuse of residual steam (waste heat recovery) produced at sulphuric acid manufacturing plants. The rest, which is 66.7%, comes from coal as the main fuel for coal-fired power plants. From this energy profile, it can be determined that the emission intensity for electric utilities is 4.5 tCO_2e per ton of nickel. All of these emissions are contributed by burning coal for power generation.

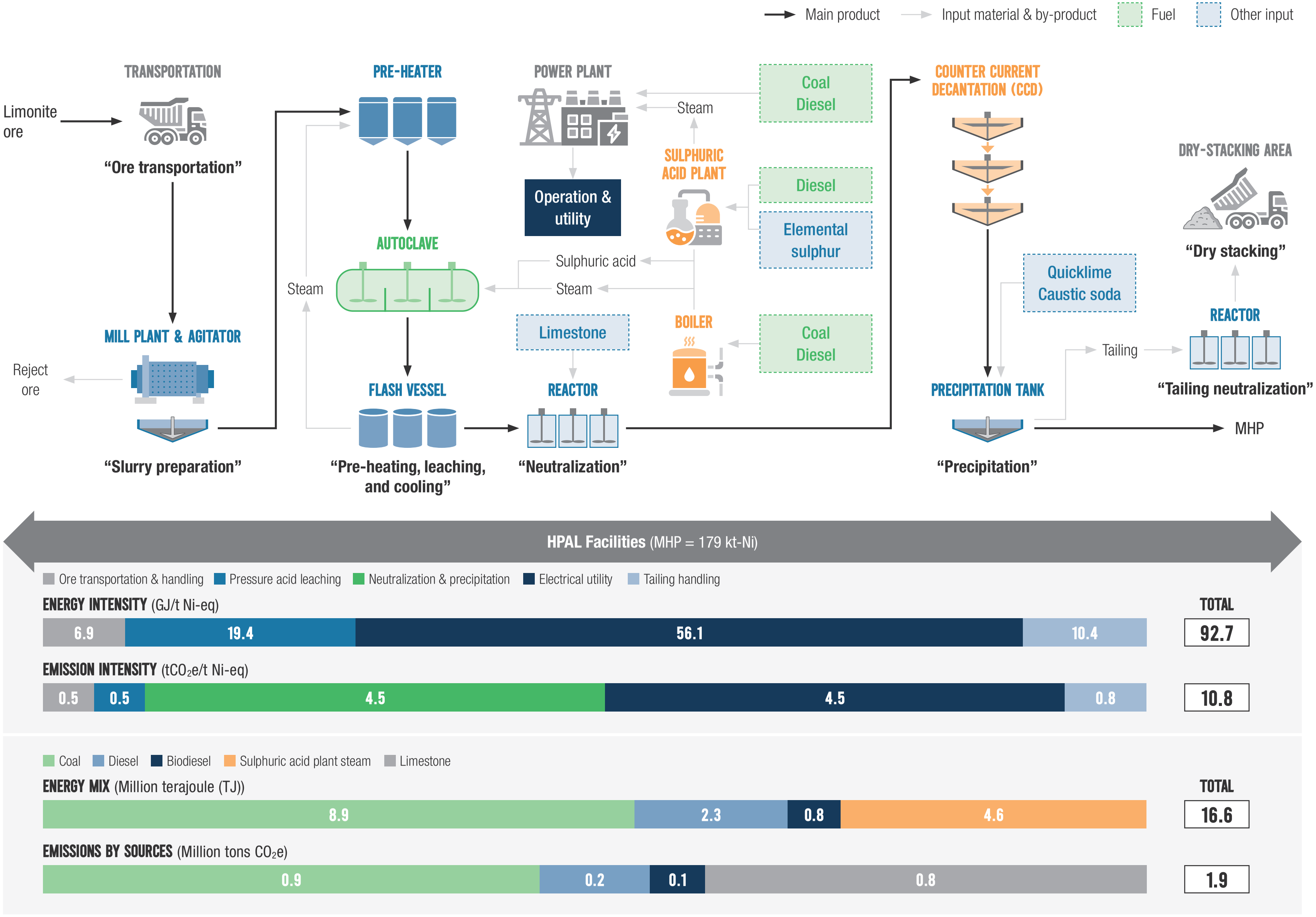
Tailings handling

In addition to producing the main product in the form of MHP, the nickel refining process using HPAL technology also generates a by-product known as tailings. Before being treated, tailings contain high levels of acid and water. Therefore, a neutralization and filtration process is carried out before the tailings are finally stored in a disposal area. Final storage of tailings typically uses the dry stacking method or open-area dumping using heavy equipment such as dump trucks, excavators, and bulldozers. The use of heavy equipment at this stage consumes 10.4 GJ/ton of Ni. Of the total energy used, 74.5% comes from diesel fuel, while the remaining 25.2% is provided by biodiesel and 0.2% by gasoline. Based on this energy profile, the emission intensity from mobile equipment operations is estimated at 0.8 tCO_2e/ton Ni.

In conclusion, it is estimated that the total energy and emission intensities from the entire MHP production process from nickel ore are 92.7 GJ/ton Ni and 10.8 tCO_2e/ton Ni, respectively. When compared to several references, this energy intensity is considered relatively low. This is due to the use of next-generation technology at HPAL facilities in Indonesia, most of which have implemented waste heat utilization. For instance, Zhang et al. (2025) reported that energy intensity for HPAL processes can reach 272 GJ/ton Ni, with a carbon footprint of 19 tCO_2e/ton Ni. These findings are based on case studies at HPAL facilities in Ramu (Papua New Guinea), Goro (New Caledonia), and Ambatovy (Madagascar).

A flow diagram of the hydrometallurgical process, accompanied by the energy intensity required and the emission intensity released at each process, is shown in **Figure 36**.

Figure 36.
Summary of the energy and emissions profile of hydrometallurgy nickel processing



2.4

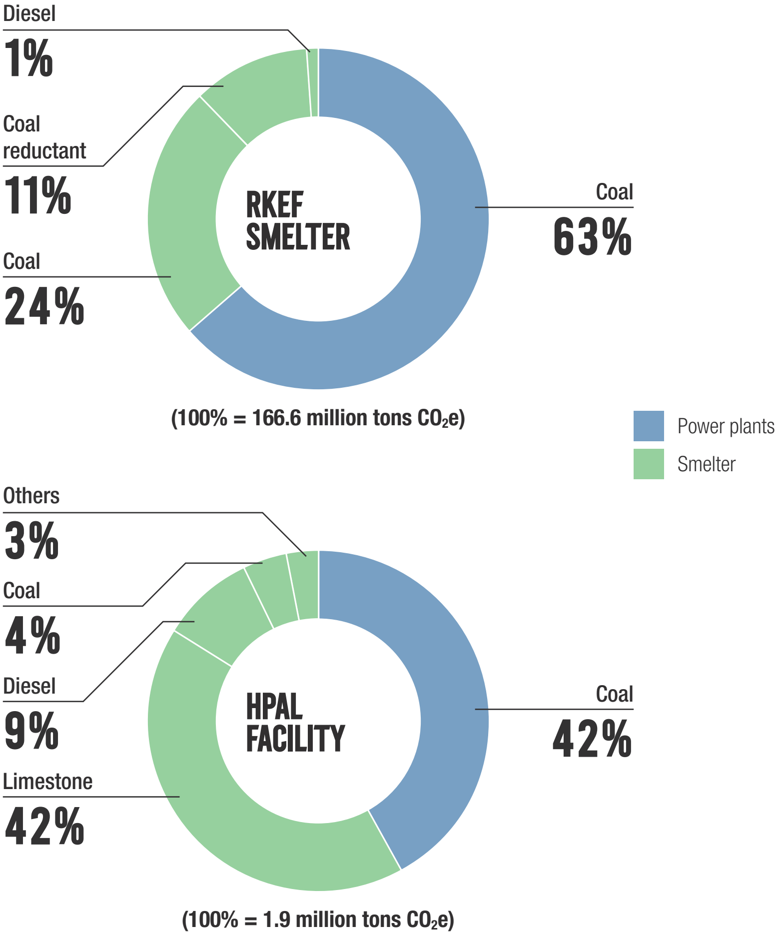
HIGHLIGHTS OF POWER PLANTS AS THE MAIN SOURCE OF EMISSIONS

As described in sections 2.2 and 2.3, nickel processing through RKEF smelters and HPAL facilities requires a very large electricity consumption. Consequently, power plants are the main source of emissions, accounting for 63.5% of the total emissions at the RKEF smelter and 42.3% at the HPAL facility, respectively. Meanwhile, the rest of the emissions come from the process of burning fuel and using materials in production facilities.

At the national level, power plants integrated with RKEF smelters are estimated to generate 106.2 million tons of CO_2e, while those supplying HPAL facilities produce 0.8 million tons of CO_2e. Combined, the total emissions from these two types of facilities reach 107.0 million tons of CO_2e, equivalent to 26% of total national power generation sector emissions.

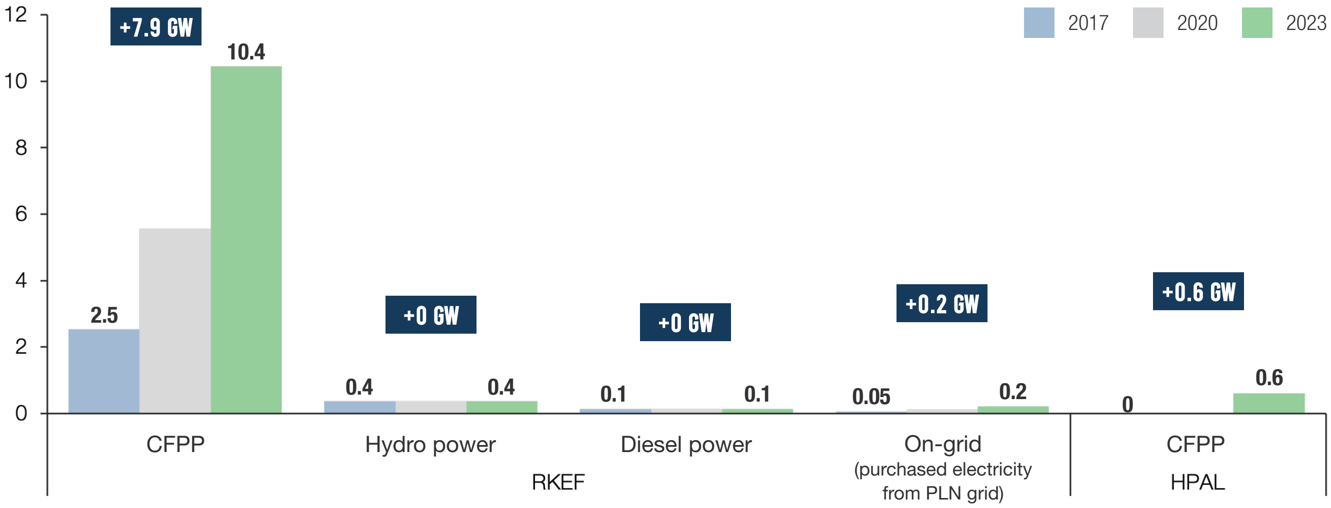
The high level of emissions from power plants in the nickel industry is largely due to the exponential growth in CFPP development. Between 2017 and 2023, the installed capacity of captive CFPP in the nickel industry increased from 2.5 GW to 11.5 GW. This total includes 10.4 GW for RKEF smelters and 0.6 GW for HPAL smelters. However, during the same period, there was no increase in other types of power plants, such as hydroelectric (HPP) or diesel (DPP) plants. Additionally, there has been no development of other low-carbon power plants, such as combined cycle power plant (CCPP), geothermal power plant (GPP), solar power plant (SPP), wind power plant (WPP). A few companies have developed small-scale solar PV systems for office use and supporting infrastructure, but these are not included in this roadmap.

Figure 37.
Nickel industry GHG emissions based on where emissions are produced



Source: Author

Figure 38.
Installed capacity of power plants in the nickel industry
GW



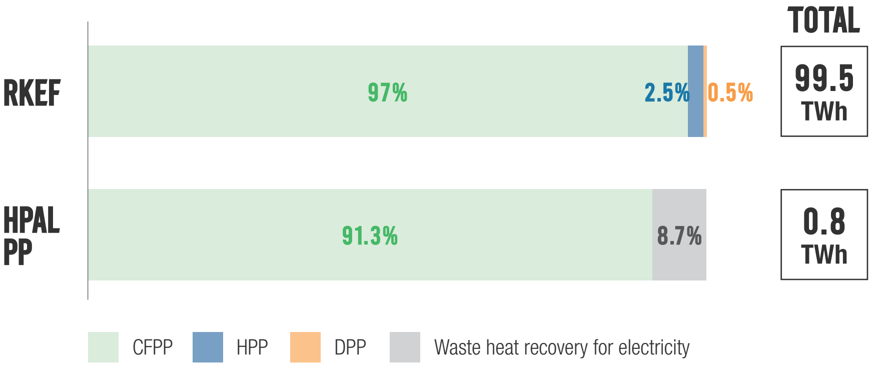
Source: Ministry of Communication and Tourism (2024), Company report

The intensive electricity demand of nickel processing is a major factor driving the massive development of CFPP, particularly for RKEF smelters. Based on data from six RKEF smelter samples, electricity consumption to produce NPI or FeNi from laterite nickel ore ranges between 35 to 50 MWh per ton of nickel.

The variation in electricity consumption among RKEF smelters is influenced by ore quality, especially nickel content, and process efficiency. Lower-grade ore requires more energy to produce the same volume of product. Meanwhile, process efficiency reflects how much energy is lost during processing. In electric furnaces, electricity consumption is also affected by the type of furnace used. Most RKEF smelters in Indonesia use the submerged arc furnace, where the electrodes are partially submerged in molten calcine. This type generally consumes more electricity than the open arc furnace, where the electrodes float above the melt. However, submerged arc furnaces offer more stable operations, as they do not cause fluctuations in power demand and have relatively lower operating costs, making them more widely adopted.

This high electricity consumption contributes to a total electricity usage of 100.3 TWh by the nickel industry nationwide. In the context of decarbonization, this figure highlights the significant challenge in finding clean energy alternatives that can reliably meet this demand without disrupting production.

Figure 39.
Electricity mix in the nickel industry
%



2.5

DECARBONIZATION EFFORTS THAT HAVE BEEN IMPLEMENTED

The mapping of decarbonization efforts was carried out in 2024 through interviews with representatives from 20 nickel mining and processing companies. The results showed that efforts capable of significantly reducing emissions are still rarely implemented. On the contrary, efforts with relatively small emission reduction impacts are the most commonly applied. This is due to the fact that the nickel industry is still relatively new. As a result, efforts with high emission reduction potential—such as the use of clean energy for production activities—are generally still in the assessment stage.

The most widely adopted decarbonization effort among the sampled companies is the use of biofuels (BBN) as fuel for heavy equipment in mining and smelters. Biofuels are also beginning to partially replace diesel fuel in generator sets (gensets) at mining sites. The biofuels used are palm oil-based biodiesel types B30 and B35. This is in line with the Ministry of Energy and Mineral Resources Regulation No. 12 of 2015, which mandates a minimum 30% blend starting in 2020, and the Circular Letter of the Directorate General of New and Renewable Energy and Energy Conservation (EBTKE) No. 10 of 2022, which raised the requirement to 35% as of February 2023.

At HPAL facilities, the reuse of waste heat from sulphuric acid production is a practice that has been implemented by most companies, although at varying scales. This effort has proven effective in reducing coal combustion used to supply heat for the high-pressure leaching process in autoclaves.

Another widely practiced decarbonization effort is tree planting, both within industrial areas—such as the development of Green Open Spaces (RTH)—and outside of them, through initiatives like land restoration programs. Nickel mining companies also conduct tree planting on former mining lands as required by Law No. 3 of 2020, following implementation guidelines outlined in Minister of Energy and Mineral Resources Decree No. 1827 of 2018. It is important to note that tree planting does not reduce emissions in absolute terms, but instead removes emissions from the atmosphere (removal).

Some companies have begun experimenting with more significant decarbonization actions. In mining operations, there has been an effort to electrify dump trucks, which has begun to be implemented at one nickel mine in Central Halmahera. The energy consumption of electric trucks is more efficient than conventional trucks because they use regenerative braking technology, which converts braking friction into electrical energy stored in the battery.

At RKEF smelters, some companies have also implemented excess heat utilization by channelling heat from the electric furnace and rotary kiln to the rotary dryer. The configuration of this practice can vary between companies. Companies that have not implemented this typically did not design their facilities to support such systems from the start, making retrofitting difficult.

Additionally, several companies have begun experimenting with the use of biomass as a fuel and as a reductant to replace coal. Biomass is gradually being blended into fuels for CFPP. Biomass materials such as palm kernel shells are also beginning to be used as reductants, replacing anthracite and semi-coke. Biomass is currently the most feasible option for reducing emissions from reductant materials, as alternatives like hydrogen gas remain very limited and expensive.

A decarbonization effort with significant emission reduction potential is the use of RE power plants for production processes. However, so far only one company has implemented this through the use of HPP. Several industrial zones are planning to build intermittent RE power plants, such as SPP and HPP, in order to meet national RE mix targets.

Figure 40.
Decarbonization efforts that have been implemented by the nickel industry until 2024

Adoption Level	Mining Operations	RKEF Smelter	HPAL Facilities
High adoption	**Related to production process:** • Use of Biofuel (BBN) as fuel for heavy equipment • Use of biofuel as fuel for generator sets (gensets) **Others:** Mine reclamation	**Related to production process:** Use of biofuel for heavy equipment **Others:** Tree planting and creation of green spaces	**Related to production process:** • Utilization of excess heat from sulfuric acid plant in autoclave and power generation • Use of biofuel for heavy equipment **Others:** Tree planting and creation of green spaces
Limited adoption	**Related to production process:** • Ore slurry pipeline for long-distance transport • Use of electric dump trucks • Fleet size adjustment and road conditions/terrain optimization **Others:** Installation of solar PV for support facilities	**Related to production process:** • Waste heat recovery from furnace and rotary kiln in rotary dryer (waste heat utilization) • Use of sustainable biomass-based reductant • Co-firing of biofuel in rotary dryer and rotary kiln • Co-firing of biomass in coal-fired power plant (PLTU) • Replacement of off-grid power generation with on-grid system and purchase of Renewable Energy Certificates (REC) • Use of hydroelectric power plant (PLTA) for production facilities **Others:** • Use of electric buses for workers • Installation of solar PV for support facilities	**Related to production process:** • Ore transportation from mine to smelter using slurry pipeline • Control of input ore characteristics **Others:** Installation of solar PV for support facilities
Planning stage	**Related to production process:** • Deployment of renewable energy power plant for mining equipment **Others:** -	**Related to production process:** • Installation of solar PV for production facilities • Use of natural gas as fuel for rotary kiln and rotary dryer • Use of gas-fired combined cycle power plant (PLTGU) for production facilities **Others:** -	**Related to production process:** Deployment of renewable energy power plant for production facilities **Others:** -

CHAPTER

03

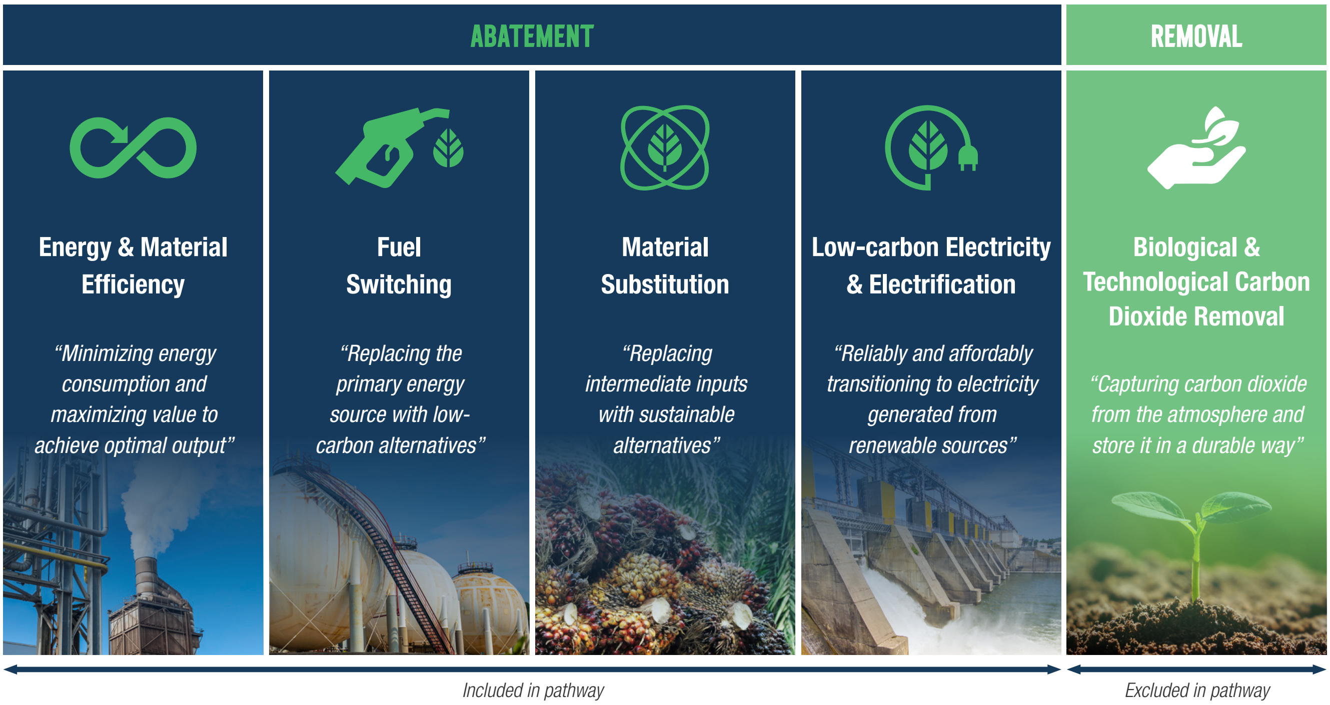
FRAMEWORK & POTENTIAL FOR DECARBONIZATION

The decarbonization strategy in this roadmap is focused on the primary extraction sub-sector using pyrometallurgy, given its significant emissions contribution. Four main approaches are considered to reduce absolute emissions:

- **Prevention and efficiency**, focusing on optimizing mass and energy balances to avoid emission-generating activities.
- **Fuel switching from high-emission fuels to lower-carbon alternatives**, taking into account the technical and combustion characteristics of each fuel.
- **Material substitution**, which involves replacing raw materials or chemical reagents in the production process to generate fewer greenhouse gas emissions.
- **Low-carbon electricity & electrification**, by promoting the use of low-carbon power generation and assessing the potential for energy substitution based on capacity and technical efficiency.

This roadmap emphasizes emission reduction through absolute GHG abatement, meaning removal efforts such as sequestration are not included in the decarbonization trajectory. Carbon capture technologies may be considered at a later stage, once emission reduction efforts have been maximized.

Figure 41.
Decarbonization strategy framework in the nickel industry



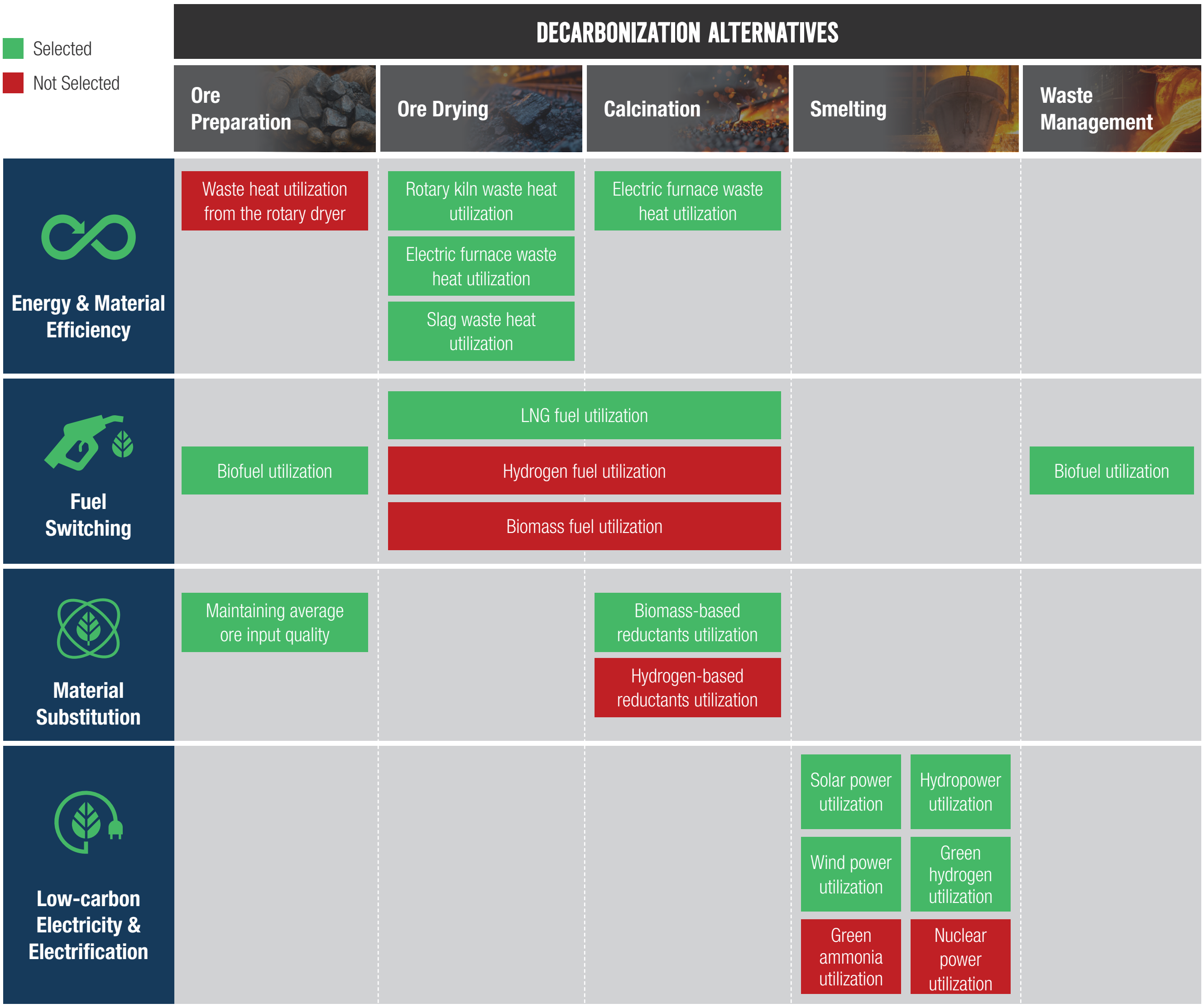
Of the four pillars of absolute emission reduction (abatement), this roadmap identifies decarbonization alternatives for each pillar based on four criteria covering impact, technology, and cost aspects:

- Potential emission reduction
- Technological Readiness Level (TRL)
- The impact of the implementation of decarbonization actions on the production process and product quality
- Large capital and operating costs

Based on TRL, some alternatives were excluded from the decarbonization scenario in this study. Only alternatives with a minimum TRL of 8 (at least in early deployment) were considered. However, an exception is made for hydrogen use as a power generation alternative in Cluster 2 (North Maluku), due to the limited availability of conventional RE sources (HPP, SPP, and WPP). Risks to existing processes and products were also taken into account.

The risk is classified into three levels: high (significant effect on product and process quality), moderate (effect on either), and low (minimal effect). In addition, risks to non-emission environmental parameters are also analyzed. High risk includes negative impacts on more than one environmental parameter, moderate on one parameter, and low if the impact is insignificant. Some selected alternatives pose significant risks. For example, biomass as a reductant faces supply uncertainty, and clean electricity use may lead to large-scale land use impacts. **Figure 42** summarizes the alternatives considered in the decarbonization scenario of this study.

Figure 42.
Alternatives to decarbonization actions selected in the roadmap



🟩 Selected
🟥 Not Selected

	DECARBONIZATION ALTERNATIVES				
	Ore Preparation	Ore Drying	Calcination	Smelting	Waste Management
Energy & Material Efficiency	🟥 Waste heat utilization from the rotary dryer	🟩 Rotary kiln waste heat utilization 🟩 Electric furnace waste heat utilization 🟩 Slag waste heat utilization	🟩 Electric furnace waste heat utilization		
Fuel Switching	🟩 Biofuel utilization	🟩 LNG fuel utilization 🟥 Hydrogen fuel utilization 🟥 Biomass fuel utilization			🟩 Biofuel utilization
Material Substitution	🟩 Maintaining average ore input quality		🟩 Biomass-based reductants utilization 🟥 Hydrogen-based reductants utilization		
Low-carbon Electricity & Electrification				🟩 Solar power utilization 🟩 Hydropower utilization 🟩 Wind power utilization 🟩 Green hydrogen utilization 🟥 Green ammonia utilization 🟥 Nuclear power utilization	

3.1

ENERGY EFFICIENCY

Pillar 1

Energy Efficiency

(waste heat utilization)

	Alternatives to decarbonization action	TRL	Information	Availability	Process Risk
🟥	From rotary dryers to ore stockpiles	3	It has not been implemented, although it is possible	14% of the heat in exhaust gases can be utilized	Medium
🟩	From rotary kiln to rotary dryer	9	Have been implemented by a minimum of 2 RKEFs	14% of the heat in exhaust gases can be utilized	Low
🟩	From electric furnace to rotary dryer	9	Have been implemented by a minimum of 2 RKEFs	34% of the heat in exhaust gases can be utilized	Low
🟥	From electric furnace to rotary kiln	7	Have been implemented by a minimum of 1 RKEF	34% of the heat in exhaust gases can be utilized	High
🟩	From slag to rotary dryer	8	Has been applied by at least 1 RKEF and many steel processing plants	20% of the heat in the exhaust gases can be utilized	Low

🟩 Terpilih 🟥 Tidak terpilih

An effective energy efficiency effort to reduce emissions and has been implemented in the nickel industry is waste heat utilization. This effort can be made both through the use of heat directly or used to generate electricity. In RKEF smelters, the potential for residual heat that can be reused can be sourced from rotary dryers, rotary kilns, electric furnaces, and tapping out slag. To determine the amount of potential heat that can be reused, this study used a typical energy balance in an RKEF smelter (Liu et al., 2016).

Rotary dryers to ore stockpiles

In the rotary dryer, approximately 23% of thermal energy is lost through exhaust gases, while only 64% is utilized for evaporating water during ore drying. The combustion gas enters at a temperature of around 800°C, and the exhaust gas exits at around 120°C. Since this exhaust temperature is well below the threshold required for drying, reusing exhaust gas within the rotary dryer is not feasible. Although the exhaust gases can technically be directed to the drying of ore in the stockpile, this option was not further explored in this study due to the potential for low efficiency due to heat loss in open spaces and additional safety risks for workers.

Rotary kiln to rotary dryer

In the rotary kiln, around 22% of thermal energy is lost via exhaust gases, while only 42% is used in the primary reactions (including the evaporation of trapped water, reduction reactions, and limestone decomposition). The exhaust gas temperature of ~250°C is not high enough to be reused within the kiln itself, which requires ≥900°C. However, it can be used as a heat source for the rotary dryer, which operates at a required temperature of ~220°C. As of 2013, two laterite nickel smelters had implemented this approach—utilizing kiln exhaust gases for the rotary dryer via a heat exchanger. This setup encountered no significant issues related to high temperature or dust, and demonstrated relatively stable operational performance. The technology is considered proven and reliable with a TRL of 9/11, and is widely used in the metal industry. However, the system's thermal efficiency is limited—only about 14% of the heat is effectively utilized, with over 80% still lost due to transfer losses and partial combustion inefficiencies. The initial investment cost is estimated at USD 6.6 million, with potential annual operational savings of approximately USD 0.9 million.

Electric furnace to rotary dryer

In an electric furnace, only 35% of the heat energy is used for the reduction and melting process, while 3% is wasted through exhaust gases at ~900°C. Since the operating temperature of the electric furnace reaches 1,550°C, the reuse of exhaust gases to the furnace is not possible. However, these exhaust gases can be used as a heat source for rotary dryers (~220°C) and rotary kilns (~850°C). The utilization of exhaust gas furnaces to rotary dryers has been applied to at least two RKEF smelters since 2013. The system is considered reliable (TRL 9/11), inexpensive, and quite flexible to temperature fluctuations and gas flows, although high-temperature dust treatment is still required. The energy efficiency of the dryer can reach ~34%, but more than 60% of the heat is still lost during transfer and partial combustion. The temperature entering the dryer can reach ~300°C, enough to evaporate the free moisture content. The initial investment is estimated at USD 9 million with operational savings of up to USD 2 million per year.

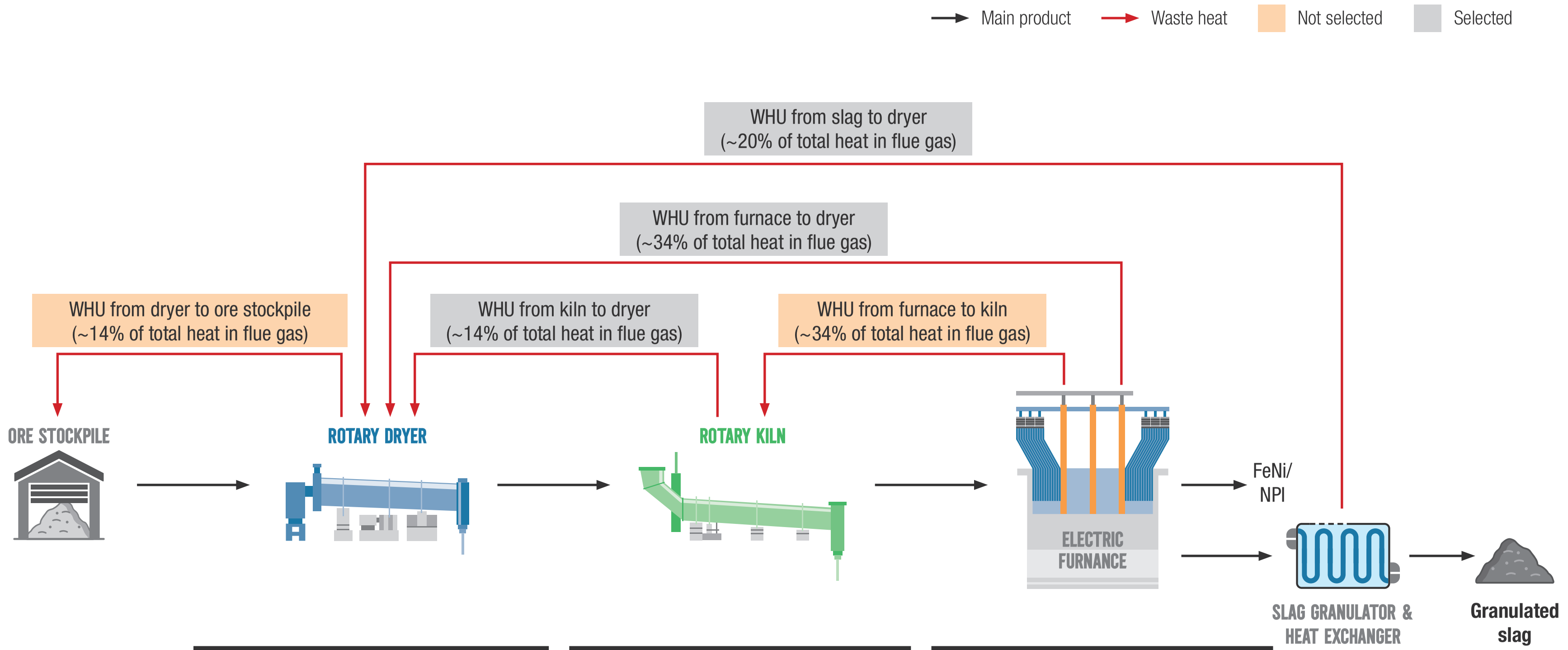
Electric furnace to rotary kiln

Meanwhile, the use of exhaust gas furnaces to rotary kilns has been tried by Eramet SLN in New Caledonia, but it is considered more technically challenging due to flue gas fluctuations due to variations in the smelting process. An ideal kiln system needs to collect exhaust gases from multiple furnaces to stabilize the flow. With these considerations, this option is considered to have a TRL of 7/11 and was not further studied in this study.

Slag tapping out to rotary dryer

The greatest potential for heat utilization is found in slag, which is estimated to contain 44% of the total system energy. Under ideal conditions, this heat can be used for rotary dryers and kilns. One example of its application is at Pacific Metals (Pamco), Japan, which utilizes hot air from the slag granulation process through a counter-current heat exchanger to heat a rotary dryer. The system also produces saturated steam and slag that are stable and marketable. Although the technology is commercially available, a full heat capture system still requires a special design, so its TRL is estimated to be 8/11. The energy efficiency achieved for rotary dryers is only about 20%, with ~80% of the heat lost during the transfer and granulation process. The hot gas fed to the dryer can reach a temperature of ~300°C which is enough to evaporate the free moisture content in the ore. The initial investment cost of the system is estimated at USD 50 million, with potential operational savings of up to USD 3.7 million per year.

Figure 43.
Energy balance and potential waste heat reuse at RKEF smelters



Energy balance			
Input (100%)		Output (100%)	
Fuel	95%	Evaporation	64%
Moisture content	3%	Flue gas	23%
Ore	2%	Dry ore	5%
Air	0.3%	Others	8%

Energy balance			
Input (100%)		Output (100%)	
Fuel	81%	Evaporation	21%
Reduction reaction	18%	Flue gas	23%
Others	1%	Calcine	35%
		Others	22%

Energy balance			
Input (100%)		Output (100%)	
Flue	55%	Slag	44%
Slagging reaction	21%	Endothermic reduction reaction	22%
Calcine input	16%	Smelting	13%
Exothermic reaction of producing CO	8%	Others	21%

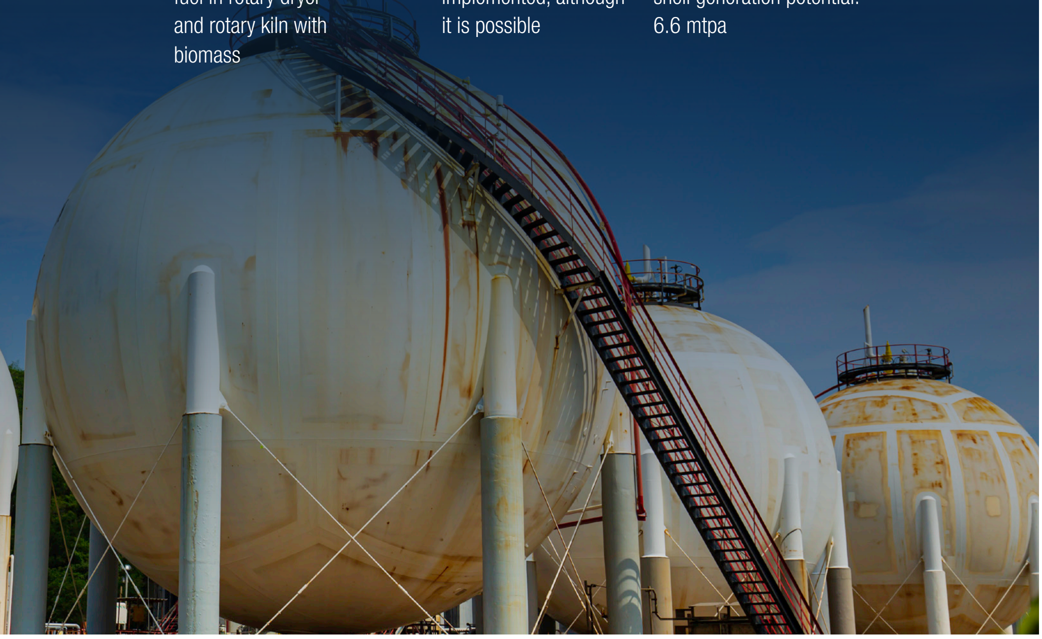
3.2

FUEL SWITCHING

Pillar 2

Fuel Switching

	Alternatives to decarbonization action	TRL	Information	Availability	Risk Process
🟩	Replacement of coal fuel in rotary dryer and rotary kiln with LNG	9	Have been implemented by a minimum of 2 RKEFs	National gas reserves are adequate and 7 LNG receiving terminals are under construction in Sulawesi and Maluku	Low
🟥	Replacement of coal fuel in rotary dryer and rotary kiln with hydrogen	3	It has not been implemented, although it is possible	Production capacity plan based on Indonesia's hydrogen roadmap: • 2035 = 1.3 mtpa • 2040 = 5.3 mtpa • 2045 = 7.9 mtpa	Low
🟥	Replacement of coal fuel in rotary dryer and rotary kiln with biomass	3	It has not been implemented, although it is possible	Annual palm kernel shell generation potential: 6.6 mtpa	Low



🟩 Terpilih 🟥 Tidak terpilih

Based on the profile of RKEF smelters, the highest emissions from rotary dryers and kilns come from the combustion of sub-bituminous coal, which serves as the primary energy source. This type of coal has a high emission factor, at 100,575 kg CO_2e/TJ (ESDM, 2018), yet remains the fuel of choice due to its relatively low average cost of approximately USD 2,932/TJ in Indonesia. Given its dominant contribution to emissions, several alternative fuels are currently being considered to replace coal.

Natural gas/LNG in rotary dryers and kilns

The first alternative is natural gas or LNG, which has an emission factor of 57,640 kg CO2e/TJ—approximately 43% lower than coal. However, with an average price of USD 12,141/TJ, operational costs would increase more than fourfold. The absence of a price cap policy for LNG and regasification specifically for the nickel industry contributes to the significant cost gap between natural gas and coal. The estimated cost of emission reduction reaches USD 215 per tCO2e, not including the required infrastructure investment for gas storage and transport, with a projected capital expenditure of USD 16,481/TJ and additional operational expenditure of USD 1,097/TJ. Several overseas smelters, such as Loma de Niquel in Venezuela and Cerro Matoso in Colombia, have already implemented this system. As a result, the technology is considered mature and is assessed to have a TRL of 9 out of 11.

Hydrogen in rotary dryers and kilns

Hydrogen produced using clean energy (green hydrogen) is also being considered as a substitute for coal, offering a zero-emission factor and a high calorific value of 120 MJ/kg (net calorific value), which exceeds that of natural gas. However, its implementation in the nickel processing industry remains extremely limited and requires further research, even though its use is beginning to be explored in the iron and steel industry. With a price of up to USD 45,193/TJ, the estimated cost of emission reduction is around USD 256 per tCO2e. Initial investment and operational costs are projected to be slightly higher—about 5%—compared to LNG. To date, there has been no application of hydrogen in either rotary dryers or kilns in the nickel sector, placing its current TRL at an estimated 3 out of 11.

Biomass in rotary dryers and kilns

Another alternative is sustainable biomass co-firing, which can prevent emissions from occurring because it is considered carbon neutral during its life cycle. With the average price of biomass (palm shell charcoal) around USD 3,490/TJ, the cost of emission reductions is estimated to be only USD 6 per tCO2e. Certain types of biomass have characteristics similar to coal, namely high carbon content and low water content. Thus, the need for additional investment is relatively small and limited to the modification of the combustion system. The main challenges of biomass are supply constraints and quality uncertainty. The low calorific value of biomass (~29.5 MJ/kg) makes the need for fuel volume much higher, thus increasing resources for transportation and storage. As of 2024, there has been no use of biomass as a fuel for rotary dryers or kilns, although co-firing has been common at coal-fired power plants. Therefore, the TRL is still estimated to be at the level of 3/11.

Availability of selected alternatives

Among the three alternatives reviewed, the replacement of thermal coal in dryers and kilns with natural gas (LNG) is prioritized in this study due to its higher technology readiness and more developed supply chain compared to the other two options.

To implement selected decarbonization efforts, the availability of natural gas reserves is not a constraint. In 2023, Indonesia has reserves of 39.4 TSCF, the majority of which are located in Maluku and Papua. Some of the natural gas is processed domestically into 16 million metric tons of LNG products in 2023. Approximately 65% of this LNG was exported, while the remainder was supplied to PLN power plants and industries such as petrochemicals, steel, and ceramics. To meet the demand from nickel smelters, an increase in LNG production will be required, supported by corresponding offtake agreements.

Another challenge lies in the availability of supporting infrastructure that is still limited in the Sulawesi and Maluku regions. Receiving terminal infrastructure with storage and regasification facilities is needed to supply LNG to the nickel industrial estate. However, until 2024, only a few LNG receiving terminals will operate in Sulawesi and North Maluku (see **Table 2**). One of the LNG terminals that operates belongs to PT Obsidian Stainless Steel, a nickel and stainless steel smelter in Konawe Regency, Southeast Sulawesi. In addition, there are also two other LNG terminals that are being planned/built by the nickel industry, namely PT Ceria Nugraha Indotama and PT Indonesia Morowali Industrial Park. Most of the other LNG receiving terminals are intended for the needs of PLN's power plants, the majority of which supply domestic needs. There are six LNG receiving terminal construction projects that are part of the Sulawesi-Maluku Cluster owned by PLN EPI and the AG&P consortium.

Table 2.
List of LNG terminal infrastructure in Sulawesi and Maluku

Region	Facility name	Kind	Status	Capacity (Mtpa)	Year of operation	Owner/Operator
Central Sulawesi (Cluster 1)	Donggi-Senoro LNG	Delivery	Operate	2.0	2015	PT Donggi-Senoro LNG (Mitsubishi, KOGAS, Pertamina, MedcoEnergi)
	LNG Hammer	Acceptance	Temporarily suspended	2.0	-	LNG Alliance
North Maluku (Cluster 2)	Ternate LNG	Acceptance	Planned	Small-scale	2026	PLN EPI & AG&P Indonesia (Sulawesi-Maluku Cluster)
South and Southeast Sulawesi (Cluster 3)	Sengkang LNG	Delivery	In construction	2.0	-	Energy World Corporation (EWC)
	Kendari LNG	Acceptance	Planned	Small-scale	2026	PLN EPI & AG&P Indonesia (Sulawesi-Maluku Cluster)
	Bau-Bau LNG	Acceptance	Planned	Small-scale	2026	
	Pomalaa LNG	Acceptance	Planned	Small-scale	2026	
Others in Sulawesi and Maluku	Gorontalo LNG	Acceptance	Planned	Small-scale	2026	
	Ambon LNG	Acceptance	Planned	Small-scale	2026	

3.3

MATERIAL SUBSTITUTION

Pillar 3

Material Substitution

	Alternatives to decarbonization action	TRL	Information	Availability	Risk Process
🟩	Maintaining average ore input quality	11	The practice of blending nickel ore is common	Target nickel content in ore: 1.73%	Medium
🟩	Replacement of coal-based reductant with biomass	8	Have been implemented by a minimum of 1 RKEF	Annual palm kernel shell generation potential: 6.6 mtpa	High
🟥	Replacement of coal-based reductant with hydrogen	3	It has not been implemented, although it is possible	Production capacity plan based on Indonesia’s hydrogen roadmap: • 2035 = 1.3 mtpa • 2040 = 5.3 mtpa • 2045 = 7.9 mtpa	High

🟩 Terpilih 🟥 Tidak terpilih

Material substitution aims to reduce energy consumption and emissions generated during the nickel production process. Materials that can be replaced include nickel ore inputs as well as other raw materials such as reductants, electrode paste, and limestone. These substitutions involve using either higher-quality variants of the same materials or entirely different alternatives. Similar to fuel switching, material substitution typically requires only minimal modifications to production facilities, and thus does not demand significant capital investment. However, this approach may lead to increased operational costs and could affect operational stability if the substitute materials are more expensive or have limited availability.

Using high grade nickel ore

The quality of nickel ore—particularly its nickel content—directly affects the energy consumption required in the processing phase. The lower the nickel grade in the ore, the greater the energy needed to produce the same final product. Additionally, lower-grade ore requires more input materials, such as anthracite and limestone, which contribute to carbon emissions during processing (see **Figure 44**). As a result, producing the same end product with lower-grade nickel ore leads to higher carbon emissions.

To address this issue, it is necessary to manage the nickel ore feed at smelters to ensure that the nickel grade remains relatively stable over time. This is especially important as some RKEF smelters in the field are already using ore with nickel content around 1.5% or even lower. On the other hand, data from the Ministry of Energy and Mineral Resources (2024) indicates that Indonesia has national reserves of high-grade nickel ore (above 1.5%) amounting to 37.5 million tons of nickel content, with 37% of that figure containing over 1.8% nickel. The average nickel grade from these reserves is 1.73%. This suggests that, with optimal ore blending, it would be possible to maintain the use of ore with this average grade until the reserves are fully depleted. Based on projected demand for nickel ore in pyrometallurgical smelters, reserves with nickel content above 1.5% are expected to be sufficient until 2038—assuming no new reserves are discovered (see **Figure 45**). Therefore, prioritizing the use of high-grade nickel ore presents a viable decarbonization strategy.

Figure 44.
Energy and material requirements at RKEF smelters
Energy (GJ/t-Ni); Material (t/t-Ni)

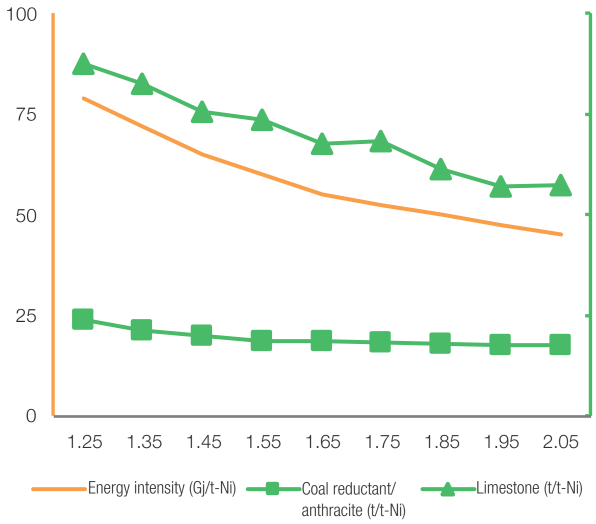
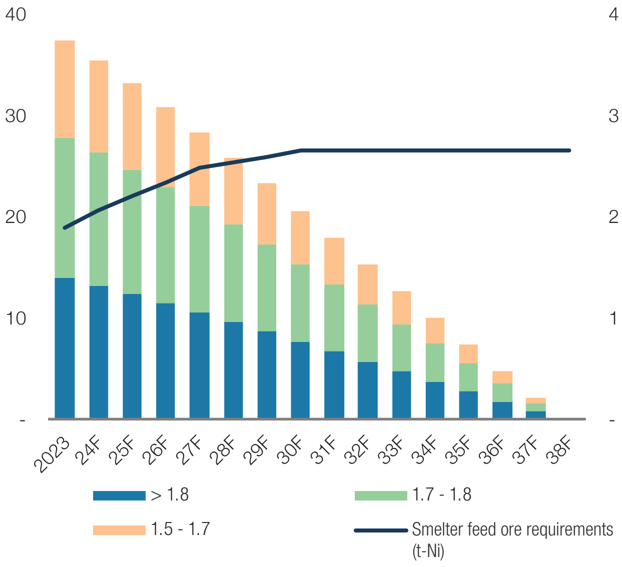


Figure 45.
National nickel reserve projections
Million tons Ni-eq



Replacement of coal-based reductants with biomass

In addition, based on the emissions profile of nickel processing through the pyrometallurgical production route, the largest source of emissions from input materials other than fuel comes from the use of coal as a reducing agent. As explained in Section 2.2, a reductant is required to reduce the Ni and Fe metals in the dried ore. Reductants with high carbon content facilitate the reduction of mineral oxides by providing sufficient carbon monoxide (CO) gas, which acts as a reducing agent within the system. Theoretically, the reaction that occurs from the reduction process in a rotary kiln can be explained as follows.

$$\underset{\text{In coal}}{C(s)} + NiO(s) \xrightarrow{800^{o}C} CO(g) + Ni(s)$$

$$CO(g) + NiO(s) \xrightarrow{800^{o}C} CO_2(g) + Ni(s)$$

$$CO_2(g) + C(s) \xrightarrow{800^{o}C} 2CO(g)$$

$$CO(g) + Fe_2O_3(s) \xrightarrow{800^{o}C} CO_2(g) + 2FeO(s)$$

Coal and its derivative products are the most widely used reductant materials due to their high carbon content, easy supply, and competitive prices. There are three types of coal-based reductants used in the nickel pyrometallurgy process, namely anthracite, semi-coke, and carbon raiser. Anthracite is the type of coal with the best quality, characterized by high calorific value and low impurities. Meanwhile, semi-coke and carbon riser are processed coal products with a carbonization process to increase carbon content and reduce pollutants.

Given that carbon content (fixed carbon) is the main parameter that determines the success of the reduction process, alternative materials to replace coal-based reductants also need to have characteristics that are not much different. However, it is also necessary to consider other parameters of calorific value, water content, and ash content that can affect the temperature profile of the rotary kiln as well as the quality of nickel products. In Table 3, it is shown that anthracite has the highest carbon content, which reaches 87.9 wt%.

Biomass is a substitute material for coal-based reductants that has been extensively researched and even implemented. Some types of biomass that have been studied for use as nickel reductants include lamtoro wood charcoal, coconut shell charcoal, palm kernel charcoal, dry rice husks, and straw charcoal. Of the five types of biomass, straw charcoal and palm oil husks have the highest fixed carbon content (see **Table 4**). In fact, its value is close to the fixed carbon content of anthracite. In addition, biomass has a higher content of volatile matter (VM), in the form of CH_4 and CO, which is higher than coal-based reductants that can help the reduction process. Moreover, its abundant availability in Indonesia makes biomass a promising alternative in the future.

Table 3.
Characteristics of coal-based reductant materials

Parameter	Anthracite[1]	Semi-coke[2, 3]	Carbon raiser[1, 3]
Moisture content (%)	2,3	5,7 – 6,0	4,7
Volatile matter (%)	7,4	8,9 – 15,0	12,6
Ash content (%)	2,5	8,0 – 16,4	13,5
Fixed carbon (%)	87,9	70,2 – 72,1	69,2
NCV (MJ/kg)	33	26,3 – 27,7	39,2
Price (USD/ton)	135	140	214

Source: [1] Petrus, et al. (2019), [2] Nurisman, et al. (2017), [3] Ministry of Energy and Mineral Resources (2021)

Table 4.
Characteristics of biomass-based reductant materials

Parameter	Lamtoro wood charcoal[1]	Coconut shell charcoal[2]	Palm kernel charcoal[3]	Dried rice husks[4]	Straw charcoal[5]
Moisture content (%)	7,0	6,2	9,1	8,7	9,8
Volatile matter (%)	17,8	26,8	8,6	54,1	6,3
Ash content (%)	4,4	2,3	6,0	23,9	3,8
Fixed carbon (%)	70,8	64,7	76,3	13,4	80,1
NCV (MJ/kg)	29,7	23,7	31,6	21,6	23 – 27
Price (USD/ton)	NA				

Source: [1] Petrus, et al. (2017); [2] Sari, et al. (2024a); [3] Sari, et al. (2024b); [4] Maksum, et al. (2018); [5] Guo, et al. (2021)

However, the use of biomass as a reductant also requires pre-treatment infrastructure to process raw materials into charcoal (biochar). The process is needed to achieve a good enough specification as shown in **Table 4**. In addition, further research and piloting is needed to achieve commercial scale use. Until 2023, there is only one company that applies biomass from palm oil shells to replace a small part of coal in the reduction process. Therefore, the TRL for this alternative is estimated to reach 8 out of 11.

Replacement of coal-based reducers with hydrogen

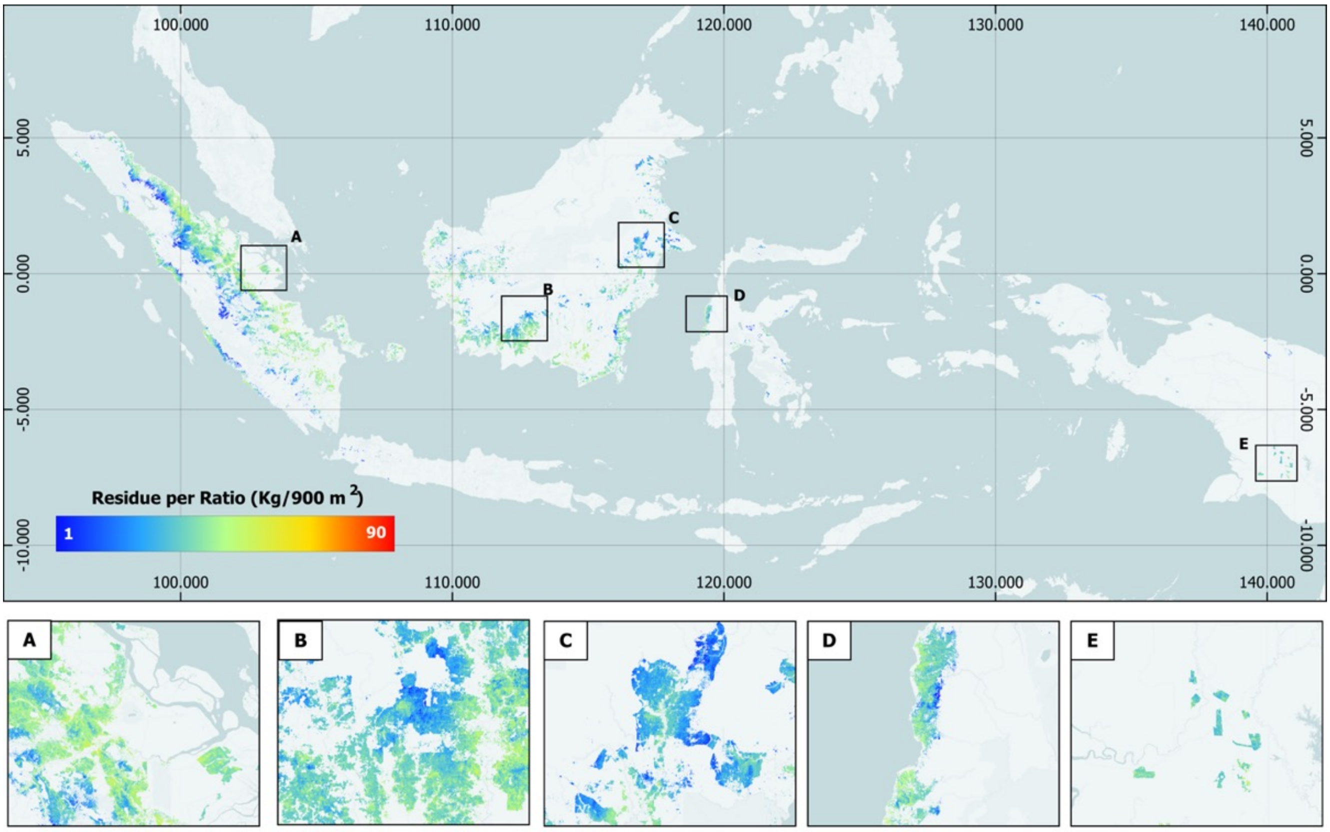
In addition to coal-based and biomass-based reductants, other alternatives such as natural gas, hydrogen, and municipal solid waste also exist. Natural gas, which contains up to 74 wt% carbon, has been used in the iron and steel industry through Direct Reduced Iron (DRI) technology, but has not yet been applied in nickel processing using the RKEF method. Meanwhile, hydrogen and municipal waste show potential as reductants but are still in the laboratory research stage. Compared to biomass, the study and application of natural gas and other alternatives as reductants remain very limited. As a result, the TRL for these options is currently estimated at 3 out of 11.

Availability of selected alternatives

Based on considerations of technology readiness, this study focuses on replacing anthracite coal reductants with biomass.

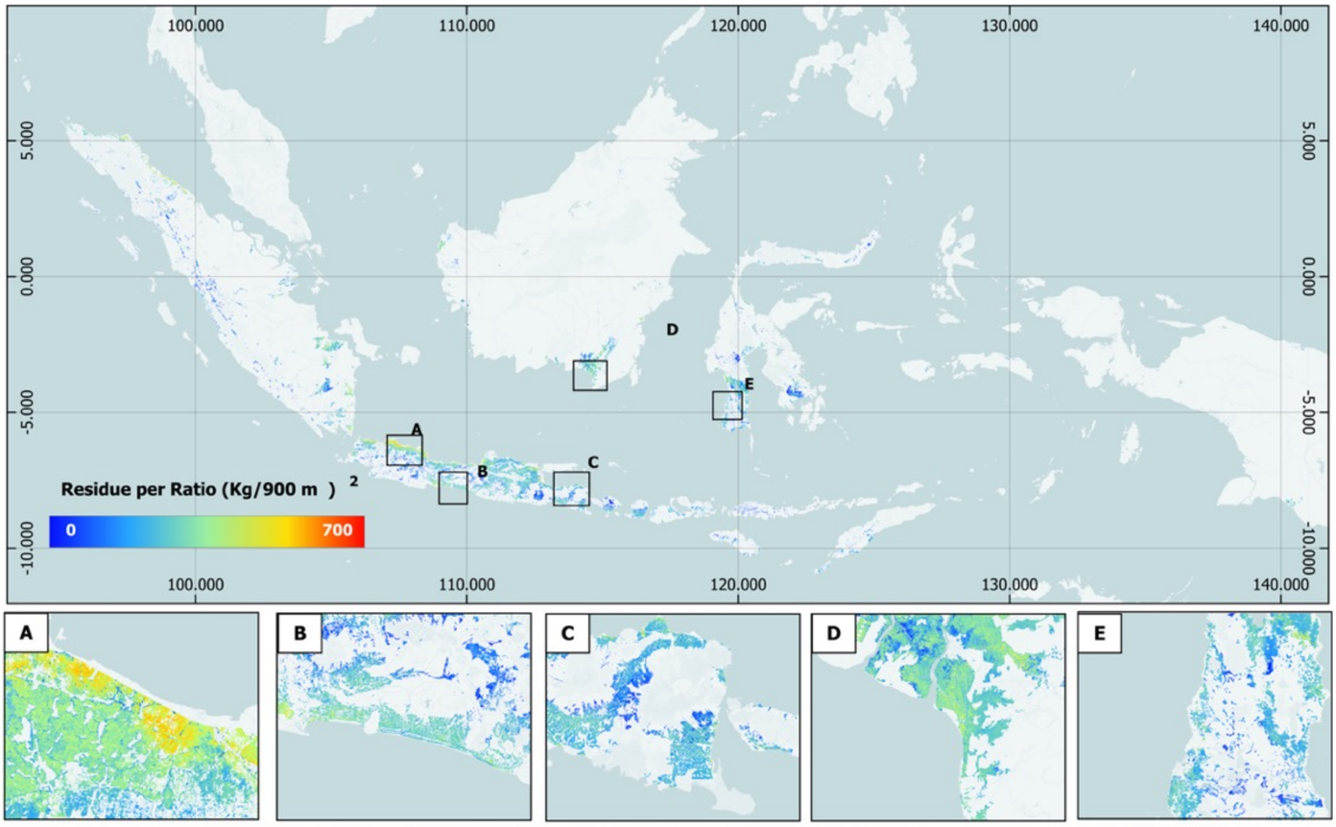
Nationally, the production potential of palm kernel shells reaches 6.56 million tons per year. However, oil palm plantations are heavily concentrated on the islands of Sumatra and Kalimantan. In contrast, the production potential of palm kernel shells in Sulawesi is significantly lower, amounting to only 58.7 thousand tons per year. Of that amount, the majority is located in West Sulawesi, as indicated by point D in **Figure 46**.

Figure 46.
Distribution of palm shell biomass waste



For rice straw biomass, the national production potential reaches 19.9 million tons, with around three million tons produced on the island of Sulawesi—primarily in South Sulawesi. The majority of the remaining volume comes from Java, which is a major rice production centre (see **Figure 47**). Although the theoretical volume is abundant, there is uncertainty on the ground due to various post-harvest practices such as open burning, or use as animal feed and organic fertilizer. Additionally, the quality of rice straw tends to be inconsistent because it is usually stored in open areas with minimal handling. This contrasts with palm kernel shells, which are produced and stored directly at palm oil mills (PKS), allowing their physical characteristics to remain more stable and controlled.

Figure 47.
Distribution of rice straw biomass waste



3.4

LOW-CARBON ELECTRICITY AND ELECTRIFICATION

Pillar 4

Low-carbon Electricity and Electrification

Alternatives to decarbonization action	TRL	Information	Availability	Risk Process
🟩 Solar Power Plant	8	In the construction phase at several smelters	The total solar power potential in the three regional clusters reaches a minimum of 160.8 TWh/year	Medium
🟩 Wind Power Plant	9	Has been applied by nickel smelters in other countries	The total solar power potential in the three regional clusters reaches a minimum of 13.4 TWh/year	Medium
🟩 Hydroelectric Power Plant	11	It has been applied by nickel smelters in Indonesia and other countries	The total solar power potential in the three regional clusters reaches a minimum of 55.9 TWh/year	Low
🟩 Green Hydrogen-based Power Plants (specifically for Cluster 2)	3	It has not been implemented, although it is possible	It is still limited, but can be produced from excess electricity from renewable energy plants	Low
🟥 Nuclear-based Power Plants	3	It has not been implemented, although it is possible	It will only be built in Sumatra and Kalimantan around 2030-2034	Low
🟥 Green Ammonia-based Power Plants	3	It has not been implemented, although it is possible	Green ammonia is produced from green hydrogen, making it less efficient	Low

🟩 Terpilih 🟥 Tidak terpilih

Based on the emission profile of nickel processing through pyrometallurgical production processes, the largest source of emissions comes from power generation. Almost all nickel smelters in Indonesia use coal-fired power plants that are managed by themselves. A small number of others use diesel and hydroelectric power.

In this study, the potential of several new renewable energies such as solar, wind, and hydro was mapped in three regional clusters. The mapping of energy potential was carried out using a machine learning method with a random forest algorithm based on more than 10 different criteria for each type of energy (see **Table 5**). The results of the energy potential mapping are then further selected with land cover maps and technical thresholds. The energy potential in forests and agricultural land is not selected to avoid the occurrence of counterproductive environmental and social risks. Technical thresholds, such as minimum sunlight intensity, are used as economic considerations of related power plant construction projects.

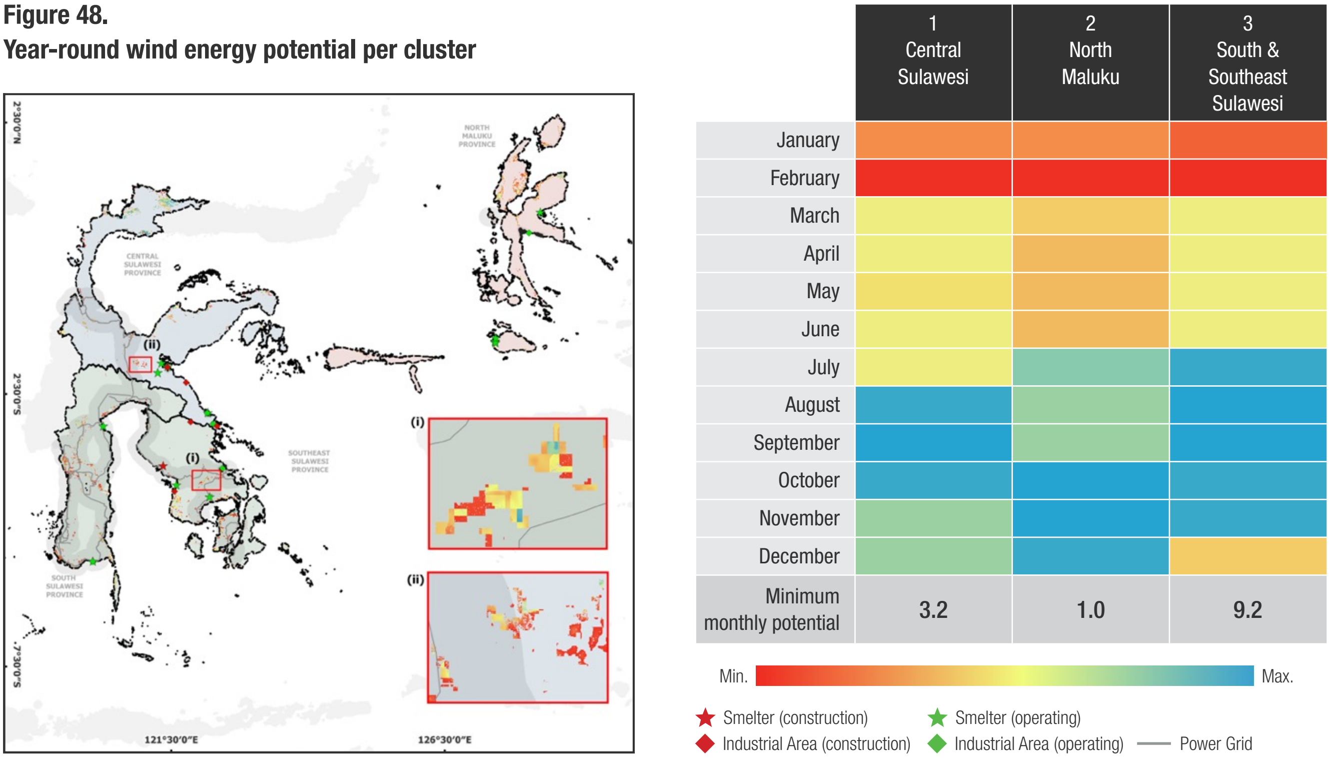
Table 5.
Criteria for spatial modeling of renewable energy potential

	Solar power				Wind power			Hydro power	
Potential Mapping Variables with Machine Learning	Global Horizontal Irradiation (GHI)	Global Tilted Irradiation (GTI)	Diffuse Horizontal Irradiation (DIF)	Direct Normal Irradiation (DNI)	Elevation	AOD	Temperature	Slope	Stream order
					Slope	Precipitation	Cloud Fraction		
	Land Surface Temperature (LST)	Aerosol Optical Depth (AOD)	Cloud fraction	Precipitation	Land aspect	Night light	Wind speed		
	Elevation	Slope	Sentinel-1 VV Polarization	Sentinel-1 VH Polarization		NDVI			
Potential Selection Criteria	Solar radiation > 550 W/m^2				Wind speed > 4 m/s			Optimization to ensure no more than 1 point selected in the same river	
	Selected: Open land, shrubland, grassland, and mining areas Not selected: Forest, farmland								

Solar Power Plant

Based on solar potential mapping, the total solar energy potential varies throughout the year across the three clusters. Cluster 3 has the highest solar energy potential compared to the other two clusters. In Cluster 3, the highest monthly solar potential can reach 18.1 TWh in September, while the lowest is 9.2 TWh in February. Cluster 2 has the lowest solar energy potential, with a maximum monthly average of only 1.7 TWh in November. Cluster 1 shows a maximum monthly solar potential of 6.6 TWh and a minimum of 3.2 TWh. Considering the fluctuating availability of solar power generation and the consistent year-round electricity demand of smelters, this roadmap uses the minimum monthly potential for the decarbonization analysis presented in Chapters 4 and 5.

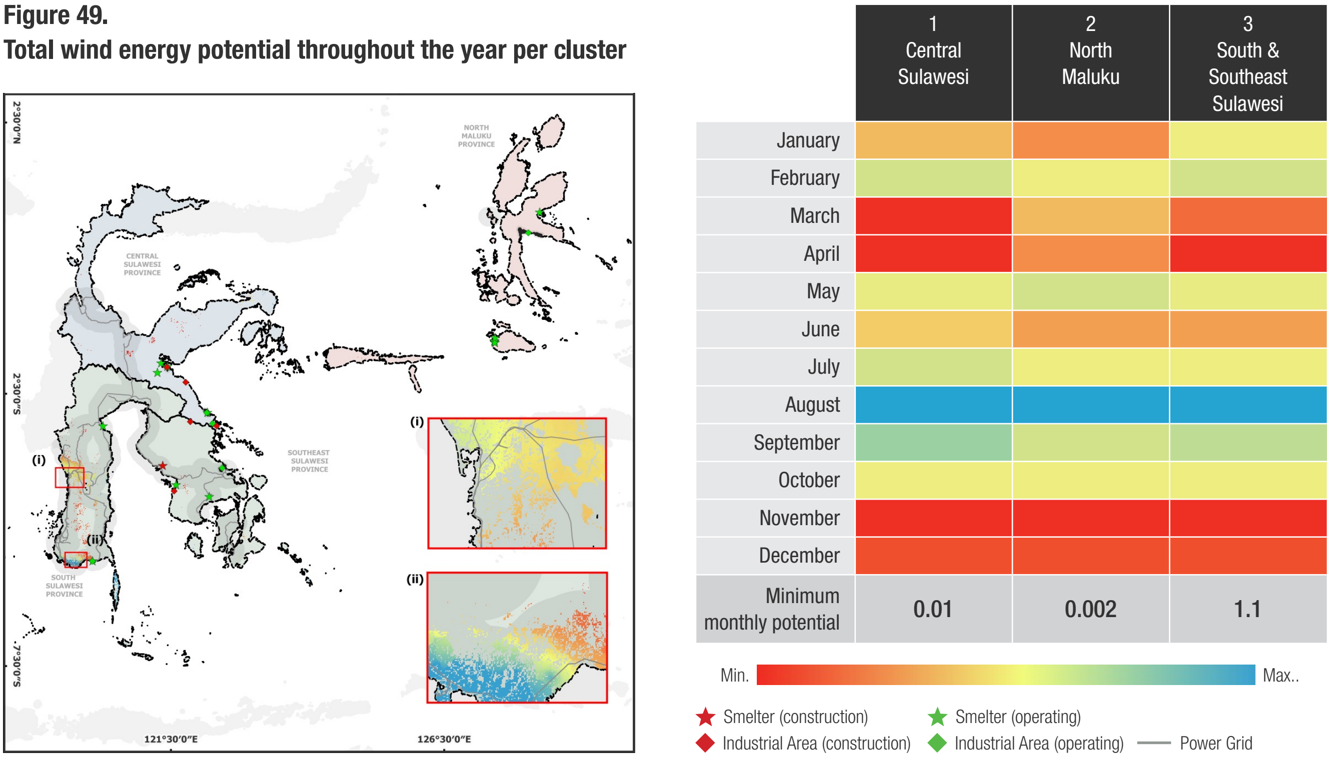
Figure 48.
Year-round wind energy potential per cluster



Wind Power Plant

The total profile of wind energy potential also showed characteristics that fluctuated throughout the year and varied across the three review clusters. Just like the potential for solar energy, Cluster 3 also shows a higher availability of wind energy potential than other clusters. Cluster 3 is expected to experience the peak of wind energy potential in August and the lowest in April. Cluster 2 has the lowest potential compared to the other two clusters, although the pattern of peaks and lows is the same, namely in August and April. The same pattern was also found in Cluster 1. For the purposes of the calculations in Chapters 4 and 5, this study uses the lowest monthly potential to ensure a stable supply of clean electricity.

Figure 49.
Total wind energy potential throughout the year per cluster



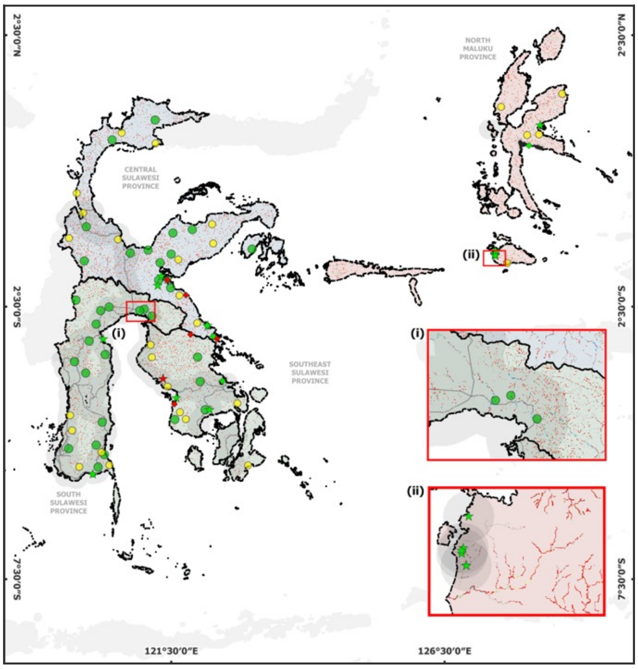
	1 Central Sulawesi	2 North Maluku	3 South & Southeast Sulawesi
January	🟧	🟧	🟨
February	🟩	🟨	🟩
March	🟥	🟧	🟧
April	🟥	🟧	🟥
May	🟨	🟩	🟨
June	🟧	🟧	🟧
July	🟩	🟨	🟨
August	🟦	🟦	🟦
September	🟩	🟩	🟩
October	🟨	🟨	🟨
November	🟥	🟥	🟥
December	🟥	🟥	🟥
Minimum monthly potential	0.01	0.002	1.1

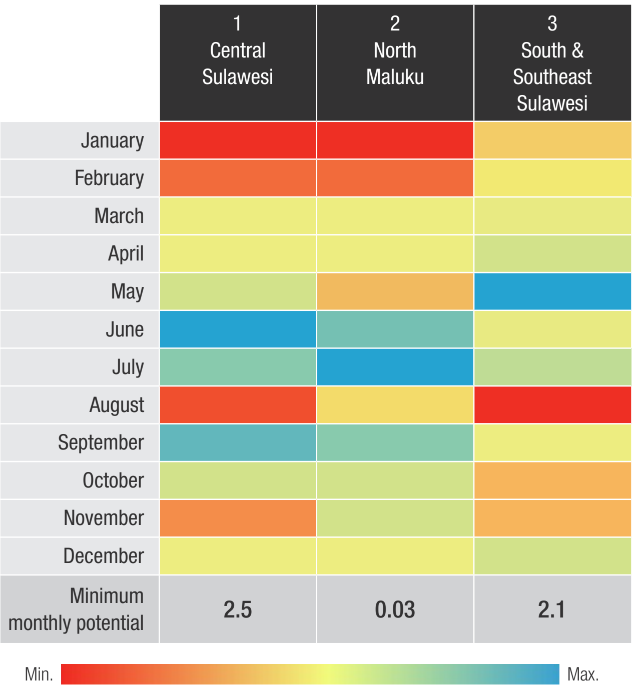
★ Smelter (construction) ★ Smelter (operating)
◆ Industrial Area (construction) ◆ Industrial Area (operating) — Power Grid

Hydroelectric Power Plant

Unlike solar and wind energy—which are mapped based on land coverage—hydropower potential is identified based on river characteristics. This identification is carried out through an optimization process to determine the most suitable indicative locations for HPP across the study area. The results show that monthly hydropower potential is more stable compared to solar and wind energy. Taking this into account—along with the fact that hydropower can be optimized through dam-based systems—this study uses average monthly potential for hydropower in its analysis. This approach differs from that of solar and wind, which are assessed based on minimum monthly potential due to their variability. The highest hydropower potential is found in Cluster 1, with an average monthly potential of 2.5 TWh. Cluster 3 follows closely with around 2.1 TWh per month. Meanwhile, Cluster 2 has the lowest potential among the three clusters, with an average monthly value of only 0.03 TWh.

Figure 50.
Total year-round hydro energy potential per cluster





	1 Central Sulawesi	2 North Maluku	3 South & Southeast Sulawesi
January	🟥	🟥	🟧
February	🟧	🟧	🟨
March	🟨	🟨	🟨
April	🟨	🟨	🟩
May	🟩	🟧	🟦
June	🟦	🟩	🟨
July	🟩	🟦	🟩
August	🟥	🟨	🟥
September	🟦	🟩	🟨
October	🟩	🟩	🟧
November	🟧	🟩	🟧
December	🟨	🟨	🟩
Minimum monthly potential	2.5	0.03	2.1

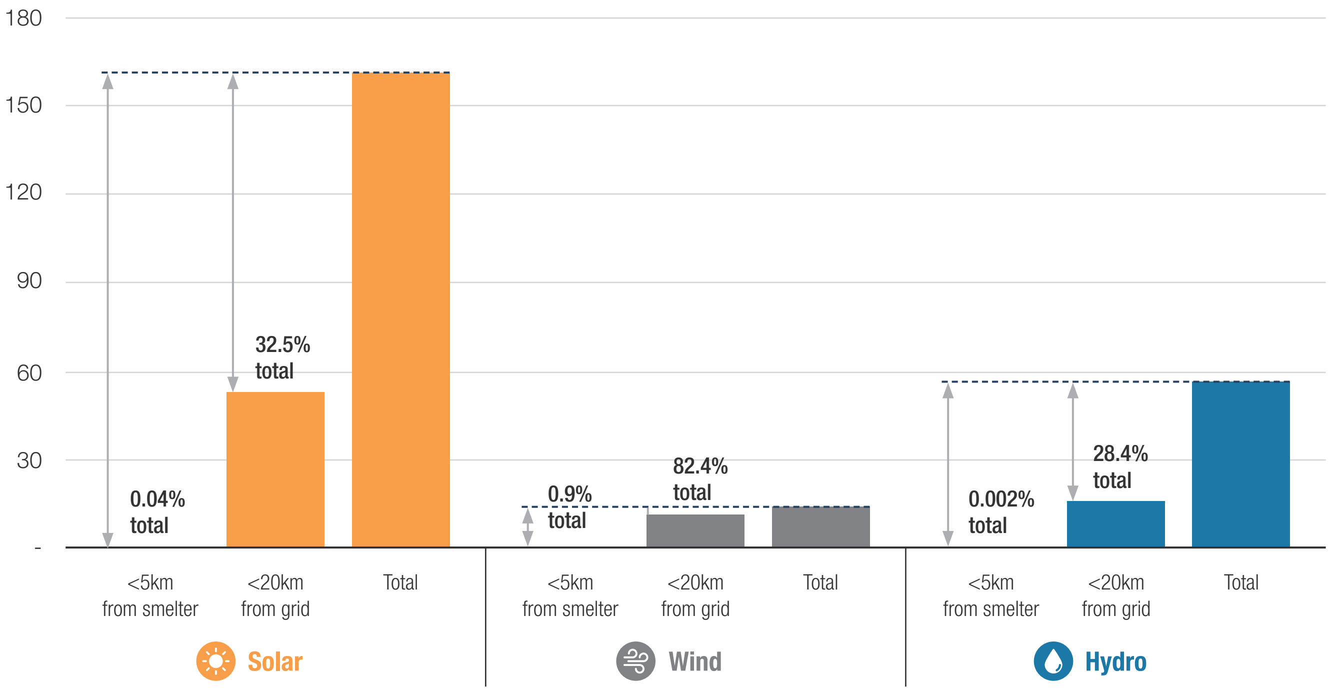
★ Smelter (construction) ★ Smelter (operating)
◆ Industrial Area (construction) ◆ Industrial Area (operating) — Power Grid

Availability of selected alternatives

Although the availability of renewable energy in Sulawesi and North Maluku is quite promising, its location far from the nickel industrial area is a challenge in its utilization. Of the total solar, wind, and hydro energy potential that has been mapped, it is known that less than 0.1% is around the smelter site (radius less than 5 km). The low potential around the smelter is caused by inconsistencies in natural conditions, such as solar radiation levels, wind speeds, land slopes, surface temperatures, precipitation, and other factors (see Table 5). In addition, many smelters are located in remote locations surrounded by forest cover, further limiting the potential of energy that can be harnessed.

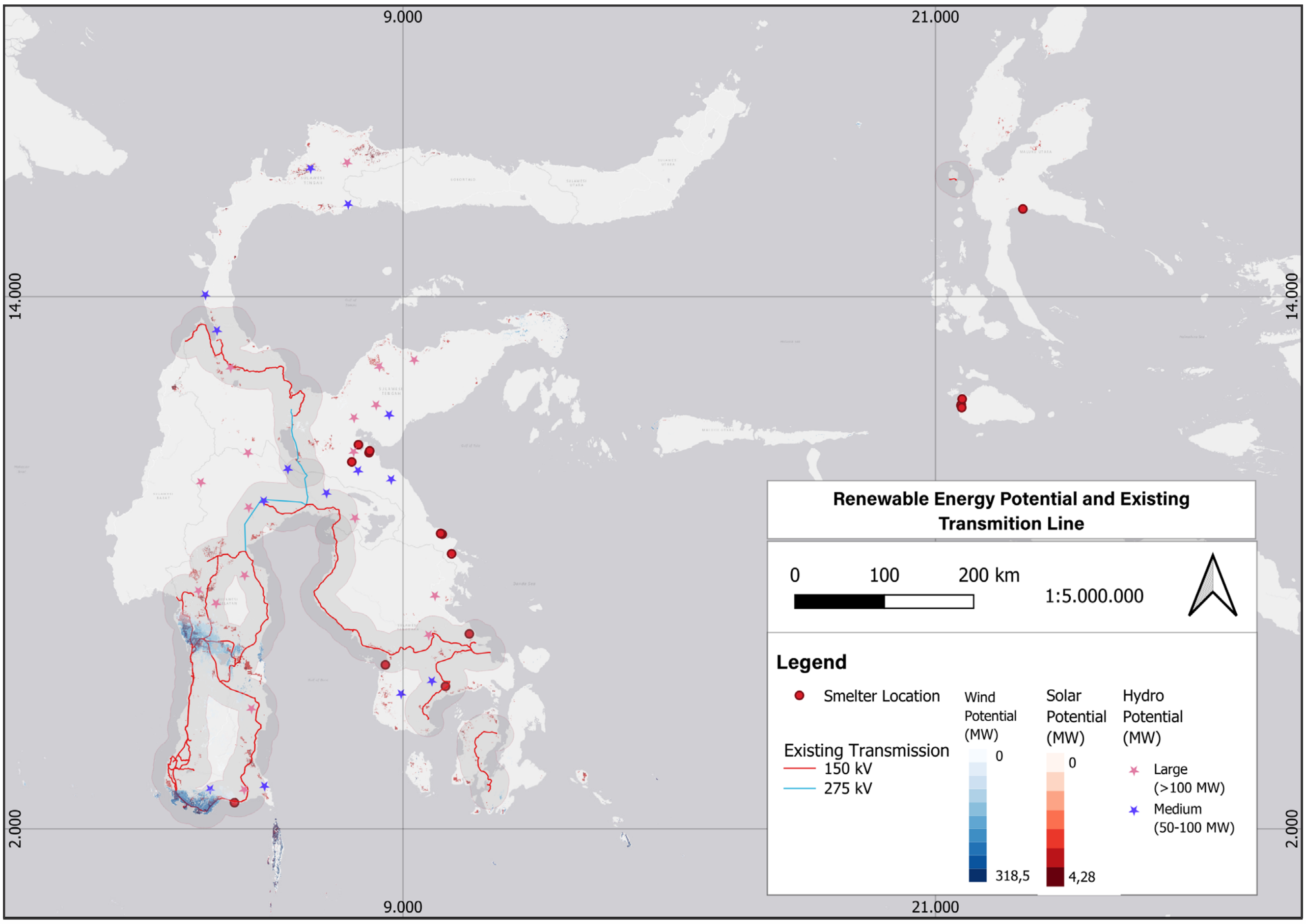
The low energy potential around the smelter led to the need to build an electricity transmission network to supply clean electricity from more distant areas. Unfortunately, the transmission network currently available covers only a small fraction of the potential of new renewable energy in the study area. Within a radius of 20 km from the transmission network in study area, there is 34.4% new renewable energy potential, with details: solar power of 32.5%, wind power of 82.4%, and hydropower of 28.4%. In addition, the transmission network has not reached most of the smelters, where only one industrial area within the study area is currently supplied by PLN.

Figure 51.
Total annual potential of renewable energy in Central Sulawesi, South Sulawesi, Southeast Sulawesi, and North Maluku, by type of energy and location
TWh/year



Among the three study area clusters, Cluster 3 (South Sulawesi and Southeast Sulawesi) is the area with the largest new and renewable energy (EBT) potential within a radius of 5 kilometres from the smelter and 20 kilometres from the electricity transmission network. Of the three types of EBT mapped in Cluster 3, as many as 49.9% are within the range of smelters and electricity transmission networks. Almost all of the wind power potential in Cluster 3, which is 83.9% of the total, is within the range as shown in **Figure 51**. Meanwhile, the potential of solar power is 44.0% and hydropower is 58.2% also within that radius. On the other hand, in Cluster 2 (North Maluku), there is only 0.3% of EBT potential within the smelter range, and there is no transmission network because the infrastructure has not been built. Taking these limitations into account, the study included the option of using green hydrogen as an alternative to reduce emissions from the power generation sector. Green hydrogen can be produced in other areas that have large EBT potential, then transported to North Maluku to gradually replace the use of coal.

Figure 52.
Distribution of renewable energy potential, electricity transmission networks, and nickel smelter industrial areas



CHAPTER

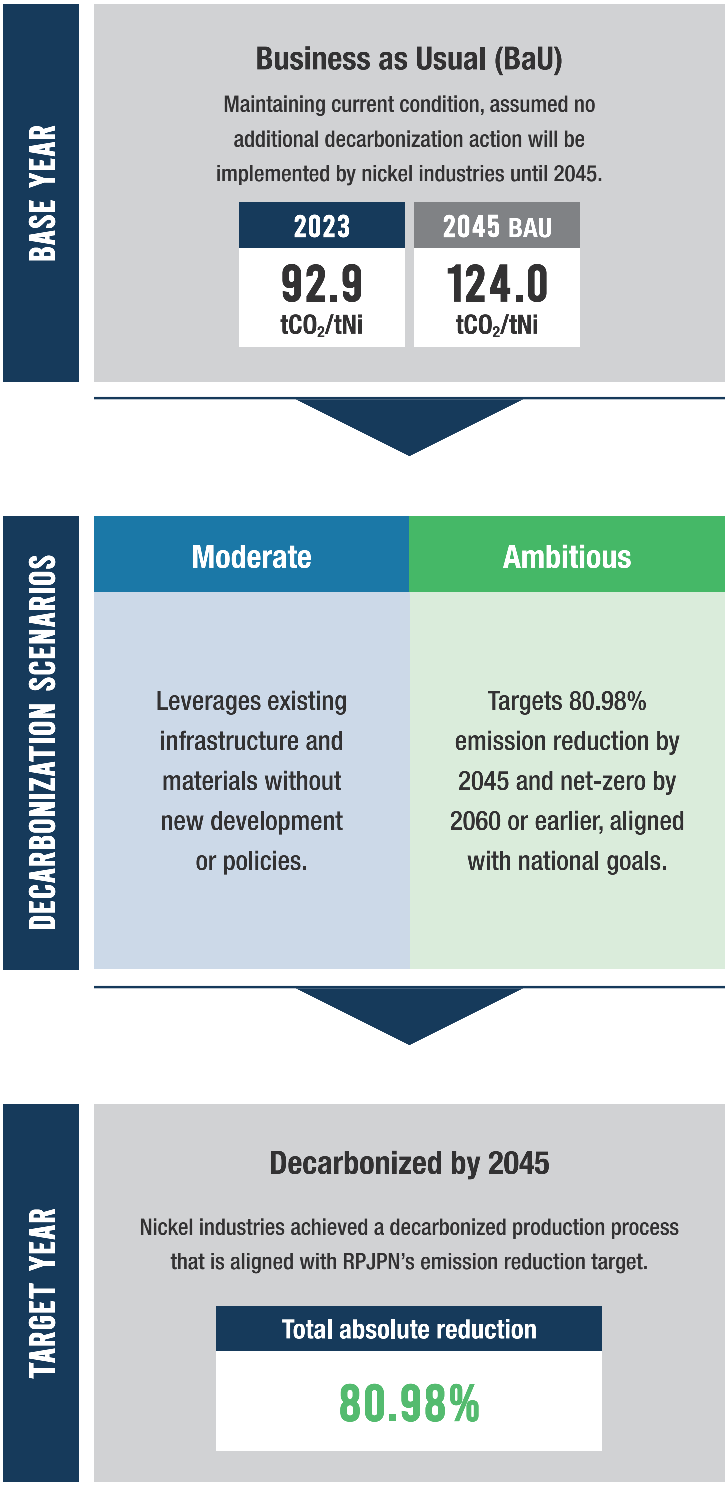
04

THE TRAJECTORY TOWARDS A LOW-CARBON NICKEL INDUSTRY

This roadmap provides a trajectory for the decarbonization of the nickel industry until 2045 which coincides with the momentum of Indonesia Emas 2045. There are three scenarios used in this roadmap, namely Business as Usual (BaU), Moderate, and Ambitious. Emission projections in these three scenarios both use a production increase database from the Ministry of Maritime Affairs in 2024 (see **Figure 32**) and include the consideration of a decrease in nickel levels in ore as the main factor affecting energy consumption (see **Figure 44**). The difference between these three scenarios lies in the assumption of decarbonization action to be implemented:

- In the **Business as Usual (BaU) scenario**, it is assumed that no new decarbonization measures will be implemented beyond those already in place as of 2023.
- In the **Moderate Scenario**, it is assumed that decarbonization will advance, but only by maximizing the use of existing infrastructure (e.g., grid, LNG terminals) and available materials, with no further infrastructure development or new decarbonization policies introduced.
- In the **Ambitious Scenario**, it is assumed that the required decarbonization actions will be implemented to reach the national GHG emission reduction target set in the 2025-2045 RPJPN, which is 80.98% against the baseline in 2045. By adopting the RPJPN target, the nickel industry will also be on track to achieve Net-Zero Emission (NZE) by 2050.

Figure 53.
Nickel industry decarbonization scenario in the roadmap



BASE YEAR

Business as Usual (BaU)

Maintaining current condition, assumed no additional decarbonization action will be implemented by nickel industries until 2045.

2023	2045 BAU
92.9 tCO_2/tNi	124.0 tCO_2/tNi

DECARBONIZATION SCENARIOS

Moderate	Ambitious
Leverages existing infrastructure and materials without new development or policies.	Targets 80.98% emission reduction by 2045 and net-zero by 2060 or earlier, aligned with national goals.

TARGET YEAR

Decarbonized by 2045

Nickel industries achieved a decarbonized production process that is aligned with RPJPN's emission reduction target.

Total absolute reduction

80.98%

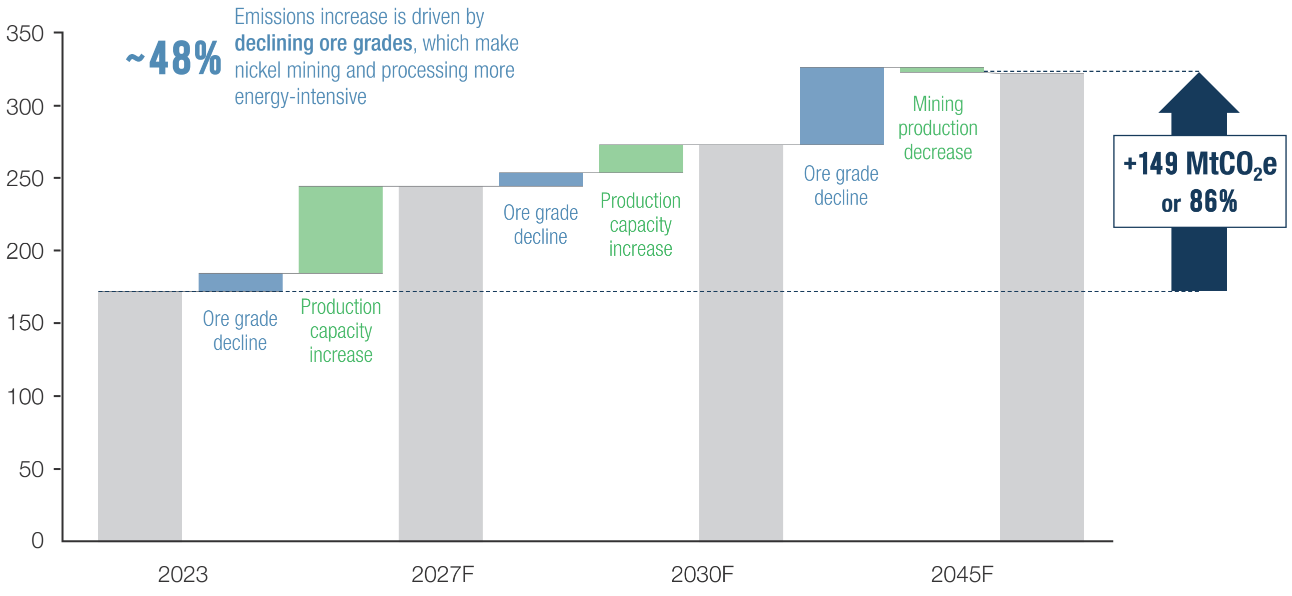
4.1

BUSINESS AS USUAL (BAU) SCENARIO

In the Business as Usual scenario, energy consumption and resulting emissions increase significantly. This is due to the absence of any new decarbonization measures that could offset the impacts of ongoing smelter expansion and the declining nickel content in ore. The projected decrease in nickel grade is based on reserve and consumption data categorized by ore grade. Assuming the industry continues to prioritize higher-grade ores, the growing scale of nickel production will inevitably lead to lower average ore quality. For saprolite nickel ore, the average nickel content is expected to decrease from 2% to 1.44% by 2039. Beyond that point, the grade is assumed to remain constant, as 1.4% represents the minimum specification required for RKEF smelters.

Using projected production levels and the average nickel content of feedstock as input data, annual emission projections can be extended to 2050. By 2045, absolute emissions are expected to increase by approximately 86% compared to 2023 levels. Of this increase, around 48% is attributed to the declining nickel grade in ore feed. Emission growth due to increased production capacity is projected to peak by 2030 and then remain relatively stable through to 2045.

Figure 54.
Projected increase in emissions in the nickel industry under BaU conditions from 2023-2045
Million tons of CO_2e

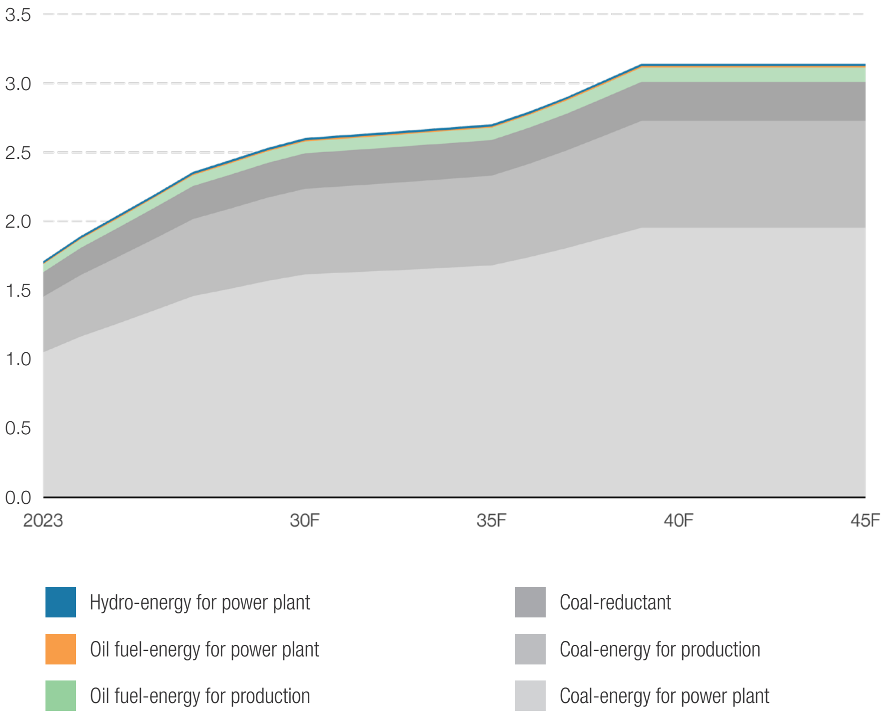


The increase in production capacity will raise the absolute energy demand in the nickel processing industry, particularly through the pyrometallurgical route. Meanwhile, the decline in nickel content in input ore will increase the energy intensity required per unit of product. As outlined in Chapter 2, coal remains the primary fuel used for heat generation in existing pyrometallurgical processes, as well as for power generation. Given both the expansion in production capacity and the reduction in nickel grade, coal demand is projected to increase from approximately 1.7 million TJ to over 3 million TJ by 2045.

Focusing on electricity generation, which is the largest source of emissions in the entire pyrometallurgical nickel production process, electricity consumption is projected to grow from 97 TWh in 2023 to 180 TWh in 2045. Under the current fuel mix, this would require coal consumption to rise from 1.05 million TJ in 2023 to 1.95 million TJ in 2045. This scenario presents a major challenge: replacing more than 180 TWh—equivalent to the output of 2,136 MW of coal-fired power generation—with renewable energy. This amount corresponds to 2.55% of Indonesia's total installed power generation capacity in 2023.

Figure 55.
Projected increase in fuel consumption in BaU conditions from 2023–2045

Million terajoules (TJ)



Referring to the RPJPN 2025–2045, the Government of Indonesia has set a target for annual emissions reduction of up to 80.98% by 2045. This study aims to develop alternative decarbonization roadmaps to achieve that reduction target. All decarbonization measures outlined in Chapter 3 are considered in formulating a set of programs deemed feasible for implementation and, as much as possible, capable of meeting the reduction goal.

To achieve this, two decarbonization scenarios are formulated: the Moderate Scenario and the Ambitious Scenario. The key difference between these two lies in the targeted capacity for implementing decarbonization alternatives, which is shaped by the limitations of existing infrastructure in order to minimize costs and technical complexity. Both scenarios are then compared to the Business as Usual scenario to assess the emissions reduction potential and the additional production costs that would arise if all decarbonization programs were implemented.

Figure 56.
Description of moderate and ambitious decarbonization scenarios

			CLUSTER 1: Central Sulawesi					**CLUSTER 2:** North Maluku					**CLUSTER 3:** South & Southeast Sulawesi				
			2025	2030	2035	2040	2045	2025	2030	2035	2040	2045	2025	2030	2035	2040	2045
ENERGY EFFICIENCY	WHU from electric furnace to rotary dryer (% plant)	Existing Plant (as of 2025)	0	20	45	70	80	0	20	45	70	80	0	20	45	70	80
		Future Plant (2026 onwards)	0	100	100	100	100	0	100	100	100	100	0	100	100	100	100
	WHU from rotary kiln to rotary dryer (% plant)	Existing Plant (as of 2025)	0	5	30	55	80	0	5	30	55	80	0	5	30	55	80
		Future Plant (2026 onwards)	0	100	100	100	100	0	100	100	100	100	0	100	100	100	100
	WHU from slag granulator to rotary dryer (% plant)	Existing Plant (as of 2025)	0	5	30	55	80	0	5	30	55	80	0	5	30	55	80
		Future Plant (2026 onwards)	0	100	100	100	100	0	100	100	100	100	0	100	100	100	100
FUEL SWITCHING	Biodiesel use in heavy equipment (blending rate)	Moderate	B30	B40	B40	B50	B50	B30	B40	B40	B50	B50	B30	B40	B40	B50	B50
		Ambitious	B30	B40	B50	B60	B70	B30	B40	B50	B60	B70	B30	B40	B50	B60	B70
	LNG use in rotary dryer and rotary kiln (% total energy consumption)	Moderate	0	15	40	65	90	0	15	40	50	61	0	13.5	13.5	13.5	13.5
		Ambitious	0	5	15	23	23	0	30	80	100	100	0	5	15	23	23
MATERIAL SUBSTITUTION	Bioreductant use (% total reductant)	Moderate	0	15	17	17	17	0	15	17	17	17	0	15	17	17	17
		Ambitious	0	10	30	75	75	0	30	80	100	100	0	10	30	75	80
	Maintain average ore grade (% Ni in ore)	All scenario	1.7	1.7	1.7	1.7	1.7	1.7	1,7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
LOW-CARBON ELECTRICITY	Utilization of solar. wind. and hydro power (% electricity mix)	Moderate	0	0.18	1.84	3.82	3.82	0	0.01	0.03	0.05	0.05	0	1.95	29.96	98.43	98.43
		Ambitious	0	1.92	29.51	90.58	98.43	0	0.01	0.82	6.76	12.81	0	2.34	31.07	90.32	98.42
	Utilization of green hydrogen (% electricity mix)	Moderate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Ambitious	0	0	0	0	0	0	0	6.07	53.55	66.85	0	0	0	0	0
	Other energy (% electricity mix)	Moderate	100	99.82	98.16	96.17	96.17	100	99.99	99.96	99.94	99.94	100	98.05	70.04	1.57	1.57
		Ambitious	100	98.08	70.49	9.42	1.57	100	99.99	93.10	39.67	20.34	100	97.65	68.93	9.68	1.58

4.2

MODERATE SCENARIO

In the Moderate Scenario, decarbonization options are chosen based on implementation readiness, with primary responsibility for execution placed on individual nickel processing companies. The capacity of each program is also constrained by the availability of necessary infrastructure and materials for decarbonization. As a result, the level of emissions reduction may vary between clusters. The adoption rate for each program is phased gradually from year to year, in order to reduce the burden of overnight capital costs and to ensure a smooth transition throughout the decarbonization process.

Figure 57.
Description of the implementation of decarbonization strategies in Moderate Scenarios

4.2.1

SCENARIO DESCRIPTION: TEMPORAL AND SPATIAL BREAKDOWN

In this scenario, 14 (fourteen) decarbonization programs are proposed for each cluster. Each type of decarbonization alternative and its adoption targets are described as follows.

A ENERGY EFFICIENCY

The energy efficiency efforts considered in this scenario are carried out through three residual heat reuse technologies, as described in Chapter 3. All clusters are assigned targets for implementing the reuse of residual heat from electric furnace to rotary dryer, from rotary kiln to rotary dryer, and from slag granulation to rotary dryer.

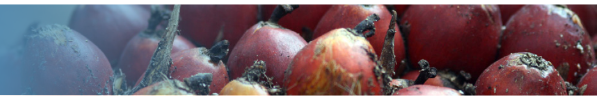
In this scenario, energy efficiency alternatives are implemented with the same adoption rate and adoption capacity across all clusters. This uniform value is chosen because energy efficiency is not significantly affected by spatial variables such as the location of nickel processing companies. However, differences in energy efficiency capacity are strongly influenced by plant layout design. Therefore, for each proposed efficiency program, separate targets are established for new and existing nickel processing plants.

For new nickel processing plants, it is assumed that the layout design can still be modified to accommodate optimal energy efficiency targets. As a result, energy targets are expected to reach 100% from the first year the residual heat reuse program is implemented. The technology for reusing residual heat from electric furnaces to rotary dryers is proposed to be implemented at 100% for nickel processing companies that will begin operating or expand their production capacity in 2027. Meanwhile, the technologies for reusing residual heat from rotary kilns to rotary dryers and from slag granulation to rotary dryers are proposed for 100% implementation by companies starting operations or expanding in 2030.

In this study, an existing nickel processing plant refers to one that began operations before the launch of the new energy efficiency program. To facilitate a smoother transition for these plants, energy efficiency targets will be gradually increased each year. This phased increase allows companies room for trial and error as well as time to ramp up residual heat reuse technology. To accommodate existing nickel processing companies where process units are spaced far apart, the efficiency capacity target is lowered to 80%. For the reuse of residual heat from electric furnaces to rotary dryers, an implementation target of 5% is proposed for 2027, increasing by 5% annually until reaching 80% in 2042. As for the reuse of residual heat from rotary kilns and slag granulation to rotary dryers, the implementation target is 5% in 2030, increasing by 5% annually to reach 80% by 2045.

B

FUEL SWITCHING



In this scenario, fuel switching efforts toward lower-carbon alternatives prioritize the replacement of diesel fuel with biodiesel and the replacement of coal with natural gas in the form of LNG. The replacement of diesel fuel can be maximized, given the high production capacity of palm oil-based biodiesel. Meanwhile, the replacement of coal in the rotary dryer and rotary kiln process units is prioritized, taking into account the limited availability of LNG capacity and the presence of alternative electricity sources to coal-fired power plants.

The replacement of diesel fuel with biodiesel is targeted to be implemented across all vehicles operated by the companies. Under current conditions, most companies already use B30-type fuel for their vehicles. From 2025 to 2029, the main priority is to ensure that all vehicles and non-electric equipment operated by nickel smelter companies use fuel with a 30% biodiesel blend. Through further research and pilot programs, it is expected that by 2030, the biodiesel blend will be increased to 40% for all vehicles and non-electric equipment in nickel smelter operations. By 2050, the biodiesel blend is planned to be raised again to 50% and is expected to be implemented across all vehicles and non-electric equipment used by nickel smelter companies.

In the replacement of coal to natural gas, each cluster has a maximum replacement capacity limit according to the capacity of existing LNG facilities around each cluster. Transition adoption will be phased out from 2028 and increase at a maximum rate of 5% increase each year, until it reaches the capacity of existing LNG terminals available.

In Cluster 1, there are two LNG terminals, namely the Donggi-Senoro Terminal and the Palu Terminal, with a total capacity of 4 mtpa. The production capacity is equivalent to 176,800 TJ, which can replace coal with sub-bituminous types of up to 90% of rotary dryers and rotary kilns.

In Cluster 2, there are no existing LNG terminals in operation. However, there are three LNG terminal facilities around Cluster 2 that are used in this scenario, namely: (1) Gorontalo FSRU (Floating Storage and Regasification Unit) facility located in Gorontalo Province with a capacity of 0.2 mtpa; (2) Amurang FSRU (Floating Storage and Regasification Unit) facility in North Sulawesi Province with a capacity of 0.1 mtpa; and (3) AG&P FSRU (Floating Storage and Regasification Unit) facility with a capacity of 2.3 mtpa. The total capacity of the three LNG facilities can reach 2.6 mtpa which is equivalent to 114,920 TJ. With this capacity, the coal needs in rotary dryers and rotary kilns can be replaced up to 60.53%.

In Cluster 3, there is one LNG terminal, namely the Sengkang Terminal with an existing capacity of up to 0.5 mtpa. This capacity is equivalent to 22,100 TJ which can replace up to 13.50% of the coal needs in rotary dryers and rotary kilns.

C

MATERIAL SUBSTITUTION

In the Moderate Scenario, the increase in emission intensity caused by the declining average nickel content in input ore is mitigated by setting a lower limit for the nickel grade of input ore. This lower limit is set at greater than or equal to 1.73%. Adoption of this program can begin as early as 2026.

In the Moderate Scenario, the replacement of coal-based reductants with biomass is carried out by limiting the amount of biomass used in accordance with existing biomass production potential, which is approximately 6.56 million tons per year (considering only palm kernel shells). As a result, the maximum percentage of coal-based reductants that can be replaced in each cluster is 16.65%. The adoption of this substitution program is expected to begin gradually starting in 2028.

D LOW-CARBON ELECTRICITY AND ELECTRIFICATION

In the Moderate Scenario, the replacement of power sources from steam power plants to renewable energy is limited by the availability of renewable energy potential located within a 20km radius of the existing electricity infrastructure as well as within a 5km radius of the smelter site. The adoption of this steam power plant replacement program will be carried out gradually from 2030 and will continue to increase until the maximum limit of potential energy availability is reached. The determination of the amount of low-carbon electricity capacity is carried out by prioritizing hydroelectric power plants and wind power plants first before then determining the replacement using solar power plants. This is done with consideration of the stability of electricity availability.

In Cluster 1, the electricity mix from hydroelectric power plants can reach a maximum of 0.7% with a total capacity of 88.54 MW. Meanwhile, the electricity mix from wind power plants can only reach a maximum of less than 0.001% with a total capacity of 7 MW. Practically, smelter companies can adopt this program by building hydroelectric power plants with a capacity of 0.1 kW/tNi and wind power plants with a capacity of 0.008 kW/tNi.

The mix of power sources from solar power plants can reach a maximum of 3.12% with a total capacity of 3.3 GW. To ensure continuous availability of electricity throughout the day, for three days, a battery system with a maximum capacity of 13.2 GW is required. Based on the current availability of battery systems that have a discharge time of 4 hours each, a total of 4 batteries with a capacity of 3.3 GW each are required. Practically, smelter companies can adopt this system with the installation of solar PV with a capacity of 3.75 kW/tNi and a battery system of 15 kW/tNi.

In Cluster 2, there is no energy potential from hydroelectric power plants. Meanwhile, the electricity mix from wind power plants can only reach a maximum of less than 0.001% with a total capacity of 4.49 MW. Practically, smelter companies can adopt this program by building wind power plants with a capacity of 0.005 kW/tNi.

The mix of power sources from solar power plants can reach a maximum of 0.05% with a total capacity of 61.7 MW. To ensure continuous availability of electricity throughout the day, for three days, a battery system with a maximum capacity of 246.81 MW is required. Based on the current availability of battery systems that have a discharge time of 4 hours each, a total of 4 batteries with a capacity of 61.7 MW each are required. Practically, smelter companies can adopt this system with the installation of solar PV with a capacity of 0.069 kW/tNi and a battery system of 0.28 kW/tNi.

In Cluster 3, the electricity mix from hydropower plants can reach a maximum of 32.88% with a total capacity of 1.24 GW. Meanwhile, the electricity mix from wind power plants can reach a maximum of 24.55% with a total capacity of 11.51 GW. Practically, smelter companies can adopt this program by building a hydroelectric power plant with a capacity of 1.68 kW/tNi and a wind power plant with a capacity of 15.68 kW/tNi.

The mix of power sources from solar power plants can reach a maximum of 41.01% with a total capacity of 13.03 GW. To ensure continuous availability of electricity throughout the day, for three days, a battery system with a maximum capacity of 52.11 GW is required. Based on the current availability of battery systems that have a discharge time of 4 hours each, a total of 4 batteries with a capacity of 13.03 GW are required. Practically, smelter companies can adopt this system with the installation of solar PV with a capacity of 17.74 kW/tNi and a battery system of 70.96 kW/tNi.

4.2.2

SCENARIO ALIGNMENT WITH RPJPN TARGETS

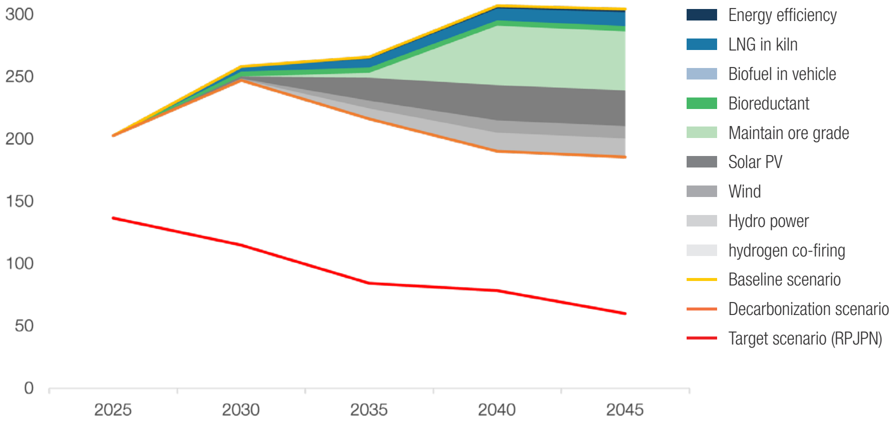
Under this scenario, emission intensity is projected to peak in 2030 and decline through to 2050. Adoption of the Moderate Scenario is estimated to reduce emissions from Indonesia's nickel industry via the pyrometallurgical route by up to 41.14% by 2050. The average emission intensity could reach 73.00 tCO_2e per ton of nickel by 2050. However, compared to the emission reduction target set in the RPJPN 2025–2045, this scenario still falls short, even by 2045. To meet the RPJPN target, an additional annual emission reduction of 124.47 million tCO_2e is still required.

By 2045, all decarbonization programs under this scenario are assumed to have reached their maximum capacity, based on current infrastructure and supply limitations. The shift to low-carbon electricity contributes the most to emission reductions, accounting for 17.60%, primarily driven by the use of solar power due to its greater energy potential across the clusters. Low-carbon material substitution contributes 16.58% to total emission reductions, achieved through setting a minimum nickel content in ore feed (15.20%) and replacing coal-based reductants with biomass (1.39%). Low-carbon fuel switching contributes 3.57%, while energy efficiency measures account for a 3.39% reduction. The capacity of energy efficiency and low-carbon material substitution programs is considered independent of smelter location, resulting in equal emission reduction potential across clusters. Differences in emission reduction performance among the three clusters will mainly depend on the availability of renewable energy resources and LNG infrastructure.

Figure 58.
Emissions reduction in Moderate Scenario

Absolute emissions

Million tons of CO_2e

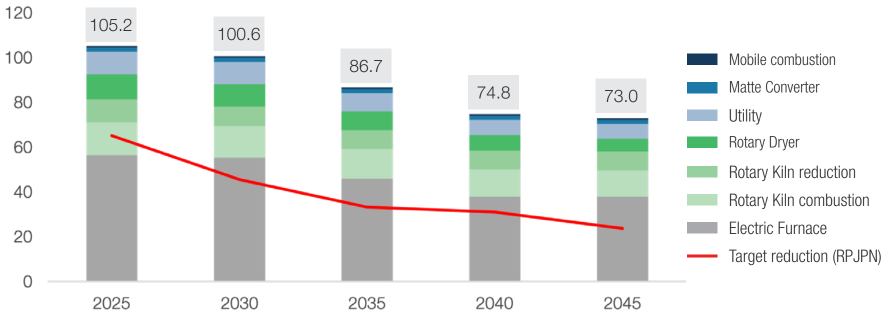


Emissions reduction compared to baseline

%

Emission intensity

ton CO_2e/ton Ni-eq

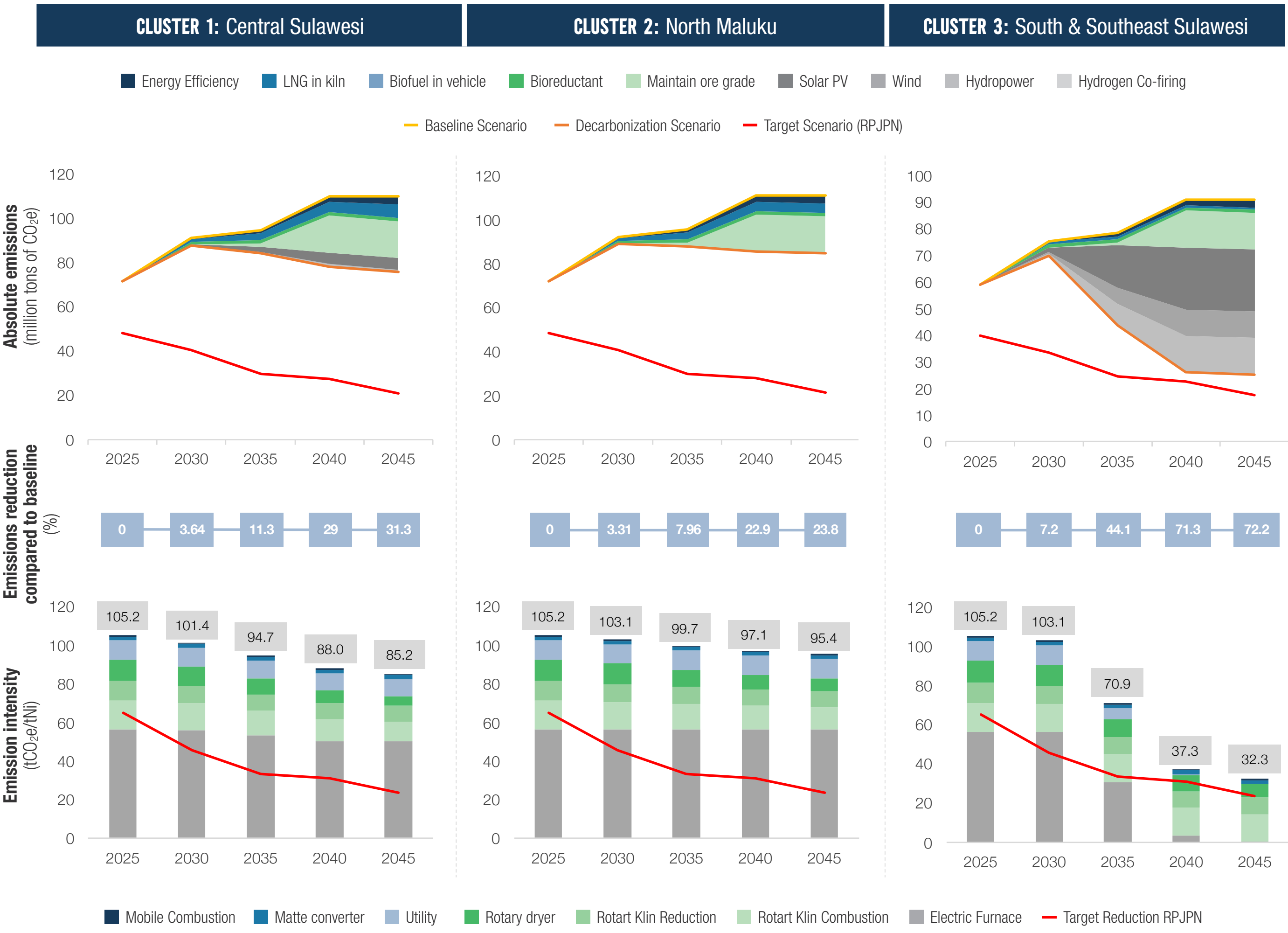


In Cluster 1, emission reduction in 2045 could reach 31.34%, with a final emission intensity of 85.15 tCO_2e/tNi. This reduction still falls short of the emission target set by the RPJPN. The limited renewable energy potential results in low-carbon electricity contributing only 5.75% to emission reductions. However, the existing LNG infrastructure in this cluster allows for a 7.00% contribution from low-carbon fuel switching—higher than the average across all three clusters.

In Cluster 2, emission reduction in 2045 is projected at 23.84%, with a final emission intensity of 94.46 tCO_2e/tNi. This also does not meet the RPJPN emission target. The limited availability of renewable energy in this cluster leads to an extremely low contribution of just 0.09% from low-carbon electricity. However, due to relatively better LNG infrastructure, fuel switching contributes 3.78% to emission reduction—again, higher than the average of the three clusters.

In Cluster 3, emission reduction in 2045 could reach 74.11%, with a final emission intensity of 32.11 tCO_2e/tNi. While this is significantly higher than the other two clusters, it still does not fully meet the RPJPN emission target. This cluster benefits from substantially greater renewable energy potential, enabling low-carbon electricity to contribute 53.30% to emission reductions. However, its LNG infrastructure is less developed compared to Clusters 1 and 2, resulting in only a 0.84% contribution from fuel switching—lower than the average across all clusters.

Figure 59.
Emissions reduction by regional cluster in Moderate Scenario



4.3

AMBITIOUS SCENARIOS

In the Ambitious Scenario, decarbonization alternatives and capacities are determined to meet the emission reduction targets set in Indonesia's RPJPN. The capacity of each program is not limited by the availability of required raw materials, except for renewable electricity capacity. This exception is made due to the challenges in building inter-island electricity transmission infrastructure. However, in this scenario, the full renewable electricity potential within each cluster will be utilized to achieve the emission reduction targets. The adoption rate for each program is also phased in gradually year by year to reduce the burden of overnight capital costs and to ensure a smooth transition.

Figure 60.
Description of the implementation of the decarbonization strategy in Ambitious Scenarios

4.3.1

SCENARIO DESCRIPTION: TEMPORAL AND SPATIAL BREAKDOWN

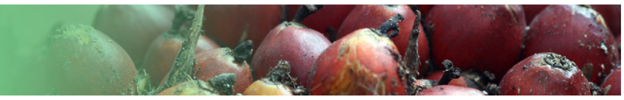
In this scenario, 15 (fifteen) decarbonization programs are proposed for each cluster. Each type of decarbonization alternative and its adoption targets are described as follows.

A ENERGY EFFICIENCY

Just like the Moderate Scenario, the energy efficiency efforts considered in this scenario are carried out through three residual heat reuse technologies. All clusters are given targets in implementing the reuse of residual heat from electric furnace to rotary dryer, from rotary kiln to rotary dryer, and from slag granulation to rotary dryer.

In this scenario, the adoption rate and capacity for energy efficiency measures are applied uniformly across all clusters. While the target capacities remain the same as in the Moderate Scenario, the pace of adoption is faster and more ambitious. Waste heat recovery from the electric furnace to the rotary dryer is expected to begin earlier than in the Moderate Scenario, specifically starting in 2026 for new plants and in 2027 for existing plants. Adoption in existing plants begins at 10% and increases progressively to reach 50% by 2030. After 2030, the adoption rate increases by 5% annually, reaching a maximum of 80% by 2035. Waste heat recovery from the rotary kiln to the rotary dryer is targeted to begin in 2026 for new plants and in 2028 for existing plants. The adoption rate for existing plants starts at 10%, rising to 50% by 2030, and continues increasing at a rate of 5% per year until it reaches 80% in 2035. Meanwhile, waste heat recovery from the slag granulator to the rotary dryer begins in 2026 for new plants and in 2030 for existing plants. For existing plants, adoption is expected to reach 50% by 2030 and then increase steadily by 5% per year until it reaches 100% in 2040.

B FUEL SWITCHING



In this scenario, the replacement of diesel oil to biodiesel is targeted to be adopted in all vehicles operated by the company. Just like the Moderate Scenario, from 2025 to 2029, the program's top priority is to ensure that all vehicles and non-electric equipment operated by nickel smelter companies use fuels with a biodiesel mix above 30%. Through further research and piloting, it is expected that by 2030, it can be set to increase the biodiesel mix to 40% for all vehicles and non-electric equipment of nickel smelter companies. Every five years, the biodiesel mix is expected to increase by up to 10%. So, by 2045, the biodiesel mix can reach 70% and be constant until 2050.

To be able to adopt it, a supply of 770.7 million litres of biodiesel are needed per year. Where, the use of biodiesel is equivalent to 306 litres per ton of nickel. By 2024, the realization of Indonesia's biodiesel production will reach 13.9 billion litres. Of the total biodiesel production, as many as 27.4 million litres of biodiesel were exported. Thus, taking into account the overall biodiesel demand for the nickel industry taken from the proportion of existing exports, an additional biodiesel production of 743 million litres is needed, without disrupting the absorption capacity of other industries.

For the program to replace coal fuel with natural gas, the targeted capacity is determined by first maximizing the use of electricity from renewable energy sources. After the renewable energy potential in each cluster is maximized, the LNG replacement capacity is limited to the achievement of emission reduction targets.

In Clusters 1 and 3, it is expected that there will be a replacement of coal fuel in rotary dryers and rotary kilns up to 23%. The increase in the adoption target will be carried out gradually from 2030 by 5% and increase by 3% per year until reaching the maximum in 2038. To be able to meet this target, a maximum of 1 mtpa of LNG is needed in Cluster 1 and 0.8 mtpa in Cluster 3. This value is equivalent to 1.06 tons of LNG/tNi.

In Cluster 2, given the limited potential to reduce power-related emissions, a greater capacity for LNG substitution in smelters is required to provide an offset. The full replacement of coal in rotary dryers and rotary kilns is targeted by 2040. Adoption should also proceed at a faster pace, with 30 percent of coal use in these units expected to be replaced by LNG as early as 2030. The increase in adoption capacity is expected to increase by up to 10% per year, reaching a maximum by 2037. To be able to meet this target, a maximum of 4.1 mtpa of LNG is needed, which is equivalent to 4.6 tons of LNG/tNi.

With the total existing LNG infrastructure capacity of up to 7.1 mtpa around the three review clusters, the total LNG needs of the three clusters of 5.9 mtpa can still be met.

C MATERIAL SUBSTITUTION

Just like in the Moderate Scenario, the increase in emission intensity from the decrease in the average nickel content in the input ore is prevented by setting the lower limit of the nickel content in the input ore. The lower limit of the nickel content of input ore is set to be more than or equal to 1.73%. The adoption of this program is expected to start in 2026.

In the Ambitious Scenario, the replacement of coal-based reductants with biomass is carried out more aggressively to meet the expected emission reduction targets. In Clusters 1 and 3, where sufficient renewable energy potential is available to reduce emissions from electricity use, the share of coal reductant replacement reaches 80%. Adoption begins gradually in 2030 at 10% and increases by 4% per year to reach 30% by 2035. From 2035 onward, the adoption rate is expected to accelerate to 9% per year, reaching 75% by 2040. After 2040, the adoption continues at a slower pace of 1% per year. At peak adoption, biomass demand for coal reductant replacement could reach 3.10 million tons in Cluster 1 and 2.57 million tons in Cluster 3. This corresponds to 3.49 tons of biomass (equivalent to raw palm kernel shells) per ton of nickel produced.

In Cluster 2, due to limited renewable energy potential to reduce overall emissions, the replacement of coal with biomass as a reductant must be even more ambitious. A complete 100% replacement is expected. The program could begin implementation in 2030 with an initial adoption capacity of 30%. Adoption is projected to grow by 10% annually, reaching full adoption (100%) by 2037. At maximum adoption, Cluster 2 would require biomass equivalent to 2.56 million tons per year, or approximately 4.37 tons of biomass per ton of nickel produced.

At peak adoption levels, a total of approximately 9.6 million tons of biomass equivalent to raw palm kernel shells per year would be required. When compared to the national biomass production potential, the existing capacity is still insufficient to fully meet the biomass demand from the pyrometallurgy nickel industry.

D LOW-CARBON ELECTRICITY AND ELECTRIFICATION

In the Ambitious Scenario, the replacement of electricity sourced from coal-fired power plants with renewable energy is limited only by the available renewable energy potential within each cluster. The adoption of this coal power replacement program begins gradually in 2030 and continues to increase until it reaches the maximum potential available. The prioritization of low-carbon electricity capacity is done by first allocating hydropower and wind power, before assigning solar power, taking into account the stability of electricity supply.

In Cluster 1, the electricity mix from hydropower can reach a maximum of 55.34%, with a total capacity of 2.52 GW. Meanwhile, wind power can only contribute a maximum of less than 0.23%, with a total capacity of 0.01 GW. In practical terms, smelter companies can adopt this program by developing hydropower plants with a capacity of 2.84 kW/tNi and wind power plants with a capacity of 0.15 kW/tNi.

The electricity mix from solar power plants can reach a maximum of 42.87% with a total capacity of 16.46 GW. To ensure continuous electricity supply throughout the day and for three days of storage, a battery system with a maximum capacity of 65.82 GW is required. Based on currently available battery systems with a discharge time of 4 hours each, a total of four battery systems, each with a capacity of 16.46 GW, would be needed. In practice, smelter companies can adopt this system by installing solar PV with a capacity of 18.54 kW/tNi and battery systems of 74.18 kW/tNi.

In Cluster 2, the potential for wind and hydropower is very limited. The electricity mix from hydropower can only reach a maximum of 0.34%, while wind power contributes just 0.03%. The total usable capacity is 27.38 MW for hydropower and 27.12 MW for wind power. In practical terms, smelter companies can adopt this program by developing hydropower and wind power plants with capacities of 0.031 kW/tNi and 0.030 kW/tNi, respectively.

The mix of electricity sources from solar power plants can only reach a maximum of 12.44% with a total capacity of 8.39 GW. To ensure continuous availability of electricity throughout the day, for three days, a battery system with a maximum capacity of 33.54 GW is required. Based on the current availability of battery systems that have a discharge time of 4 hours each, a total of 4 batteries with a capacity of 8.39 GW are needed. Practically, smelter companies can adopt this system with the installation of solar PV with a capacity of 9.35 kW/tNi and a battery system of 37.38 kW/tNi.

To be able to replace coal by up to 100% and achieve the emission reduction target, three other low-carbon electricity alternatives are also considered, such as nuclear, green hydrogen, and ammonia. In this scenario, green hydrogen is chosen based on its lower implementation costs compared to the other two alternatives. To achieve the emission target, the electrical energy mix from hydrogen-based plants must be able to reach 66.85% with a generation capacity of 5.1 GW or equivalent to 5.7 kW/tNi. At the highest adoption conditions, green hydrogen is needed up to 2.3 mtpa.

In Cluster 3, the electricity mix from hydroelectric power plants can reach a maximum of 56.54% with a total capacity of 2.1 GW. Meanwhile, the electricity mix from wind power plants can reach a maximum of 28.05% with a total capacity of 13.16 GW. Practically, smelter companies can adopt this program by building a hydroelectric power plant with a capacity of 2.90 kW/tNi and a wind power plant with a capacity of 17.92 kW/tNi.

The electricity mix from solar power plants can reach a maximum of 13.83% with a total capacity of 4.39 GW. To ensure continuous availability of electricity throughout the day, for three days, a battery system with a maximum capacity of 17.57 GW is required. Based on the current availability of battery systems that have a discharge time of 4 hours each, a total of 4 batteries with a capacity of 4.39 GW are needed. Practically, smelter companies can adopt this system with the installation of solar PV with a capacity of 5.98 kW/tNi and a battery system of 23.93 kW/tNi.

4.3.2

SCENARIO ALIGNMENT WITH RPJPN TARGETS

The adoption of all programs under this Ambitious Scenario is estimated to reduce emissions from Indonesia's nickel industry via the pyrometallurgical production route by up to 81.09% by 2045. The average emission intensity could reach 23.47 tCO_2e/tNi by 2050. Compared to the RPJPN emission reduction target of 80.90%, this scenario achieves that target starting from 2040 onward.

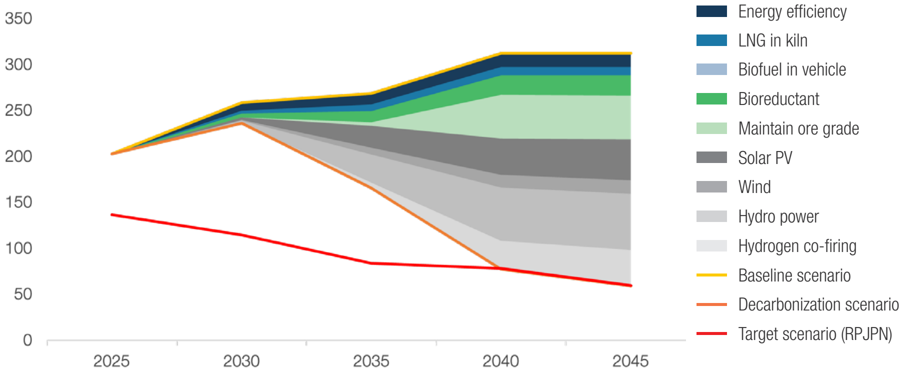
After 2045, the shift to low-carbon electricity becomes the largest contributor to emission reductions, accounting for 51.14%. Within this contribution, hydropower dominates the total energy mix, followed by solar power, hydrogen-based generation, and wind power, respectively. Low-carbon material substitution contributes 22.31% to the overall emission reduction, primarily through the establishment of a lower threshold for nickel content in input ore (15.20%) and the replacement of coal reductants with biomass (7.11%). The switch to low-carbon fuels contributes to a 2.91% reduction in emissions, which is lower than the reduction achieved in the Moderate Scenario. Meanwhile, energy efficiency efforts contribute to a 4.72% reduction. The capacities for energy efficiency programs and ore material substitution are uniform across clusters, resulting in equal emission reduction potentials in each. Differences in emission reduction performance among the three clusters are largely sensitive to the availability of renewable energy resources, which directly impact the capacity for fuel switching, low-carbon reductant replacement, and the adoption of additional renewable energy alternatives.

This scenario focuses on emission reduction from the largest source: electricity use for electric furnaces. Consequently, after 2045, the emission profile shifts, with the remaining emissions primarily originating from combustion processes in the rotary kiln and rotary dryer. These emissions are largely driven by the use of coal and LNG as fuels. Therefore, further emission reductions toward even more ambitious targets could be achieved by increasing the replacement of coal with LNG or by transitioning to other lower-carbon fuel alternatives such as hydrogen or ammonia.

Figure 61.
Emissions reduction in Ambitious Scenario

Absolute emissions

Million tons of CO_2e

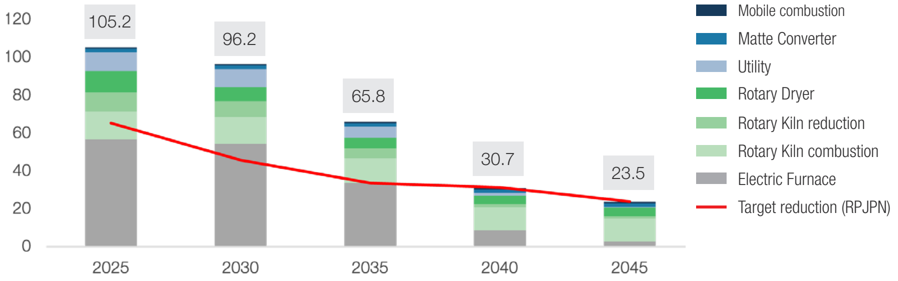


Emissions reduction compared to baseline

%

Emission intensity

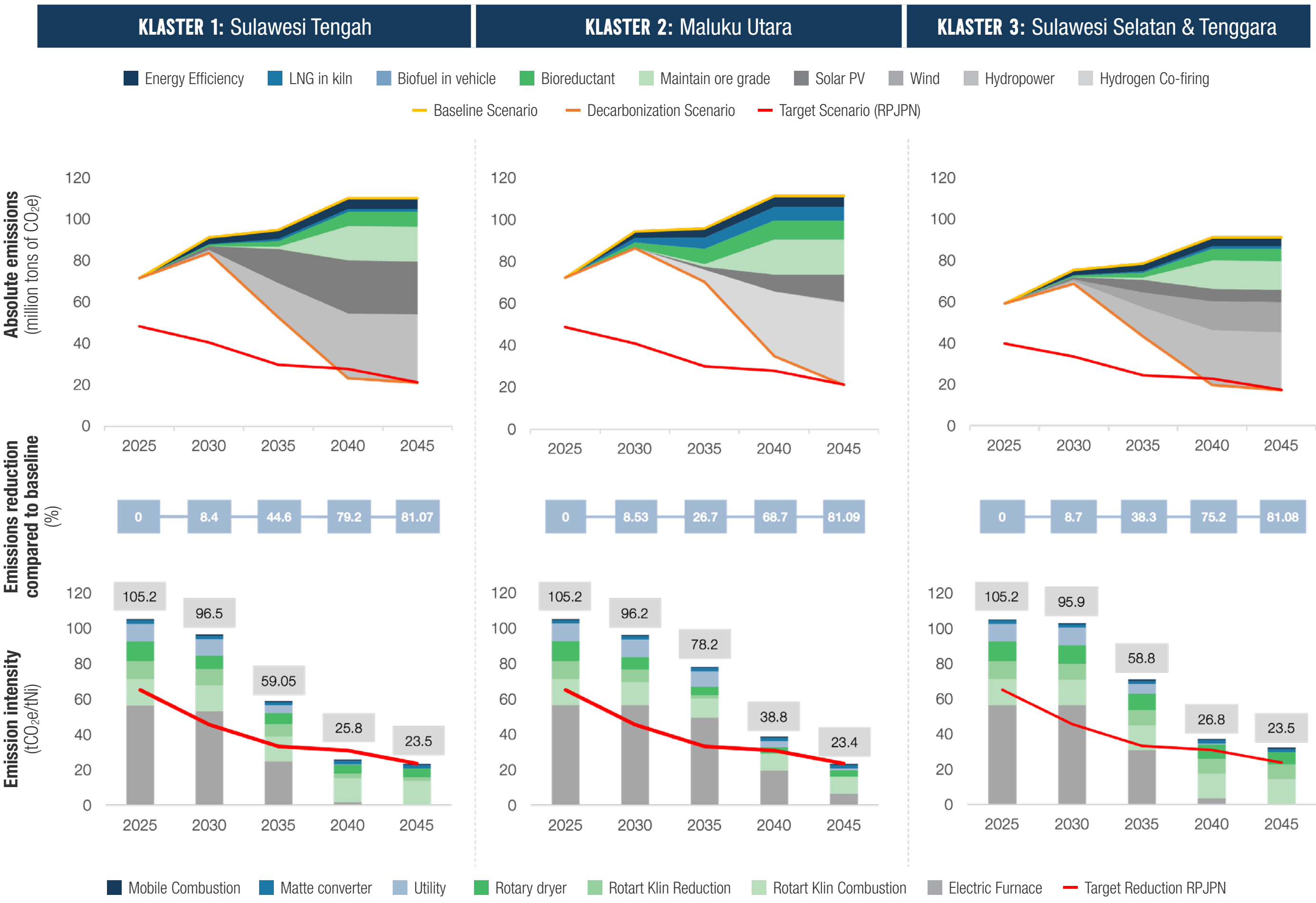
ton CO_2e/ton Ni-eq



In Clusters 1 and 3, emission reductions by 2045 can reach 81.09%, with a final emission intensity of 23.45 tCO_2e/tNi. The emission reduction performance in both clusters is sufficient to meet the RPJPN targets starting from 2040. The availability of renewable energy sources—solar, hydro, and wind—enables the complete replacement of coal-based power generation, allowing low-carbon electricity to contribute up to 53.30% of total emission reductions. As a result, a relatively small contribution of 1.33% from low-carbon fuel substitution in rotary dryers and rotary kilns is considered sufficient to meet the emission targets. This directly affects the amount of LNG and biomass required to replace coal in these units, potentially lowering the demand for these alternative fuels.

When compared to Cluster 2 which has less renewable energy potential, the contribution of emission reduction from the use of solar, hydro, and wind-based electricity is only able to reach 12.04%. As a result, significantly more LNG and biomass are required per unit of nickel production to compensate. Even with the full replacement of coal by LNG and biomass reaching 100%, the total emission reduction only reaches 45.89%. To close this emission reduction gap and meet the target, the use of alternative renewable energy—in this case, hydrogen-based power generation—is introduced within this scenario. The contribution of hydrogen power to emission reduction can reach 35.21%. Therefore, full program adoption in Cluster 2 can also achieve the 81.09% reduction target by 2045, with a final emission intensity of 23.45 tCO_2e/tNi. However, the delayed adoption of hydrogen—implemented to allow for a smoother transition—means that the target is only reached starting in 2045. Nonetheless, with Clusters 1 and 3 surpassing their emission reduction targets by 2040, the purchase of carbon credits from these clusters is considered sufficient to offset the emission gap in Cluster 2, enabling overall compliance with national reduction goals.

Figure 62.
Emission reduction column per cluster in Ambitious Scenarios



4.4

SCENARIO COMPARISON

The BaU scenario, where no additional emission reduction actions are taken, nickel processing companies in Indonesia continue operating as they currently do. Consequently, national greenhouse gas emissions increase year by year due to rising production capacity, compounded by a gradual decline in nickel content in ore input, which raises the average emissions per company. In contrast, the Moderate and Ambitious scenarios introduce various decarbonization programs to actively curb emissions from production activities.

In terms of energy efficiency, both the Moderate and Ambitious scenarios apply the same implementation rate for waste heat recovery technologies. These programs are expected to reduce energy intensity in the rotary dryer unit by up to 93% compared to the BaU condition, bringing the energy intensity down to 70 GJ/t-Ni.

For the fuel-switching program, the implementation capacity and pace differ across clusters, influenced by the availability of alternative fuels and the capacity of other decarbonization programs in each region. In Cluster 1, the Moderate Scenario assumes a higher percentage of coal-to-LNG replacement than the Ambitious Scenario. This is because the Ambitious Scenario prioritizes greater substitution of electricity sources and reductants, which are considered more cost-effective than LNG. In contrast, for Clusters 2 and 3, the Moderate Scenario applies a lower LNG adoption capacity than the Ambitious Scenario, due to more limited LNG infrastructure compared to Cluster 1. The scarcity of renewable energy in Cluster 2 necessitates greater reliance on LNG to replace coal, since LNG remains cheaper than hydrogen-based power.

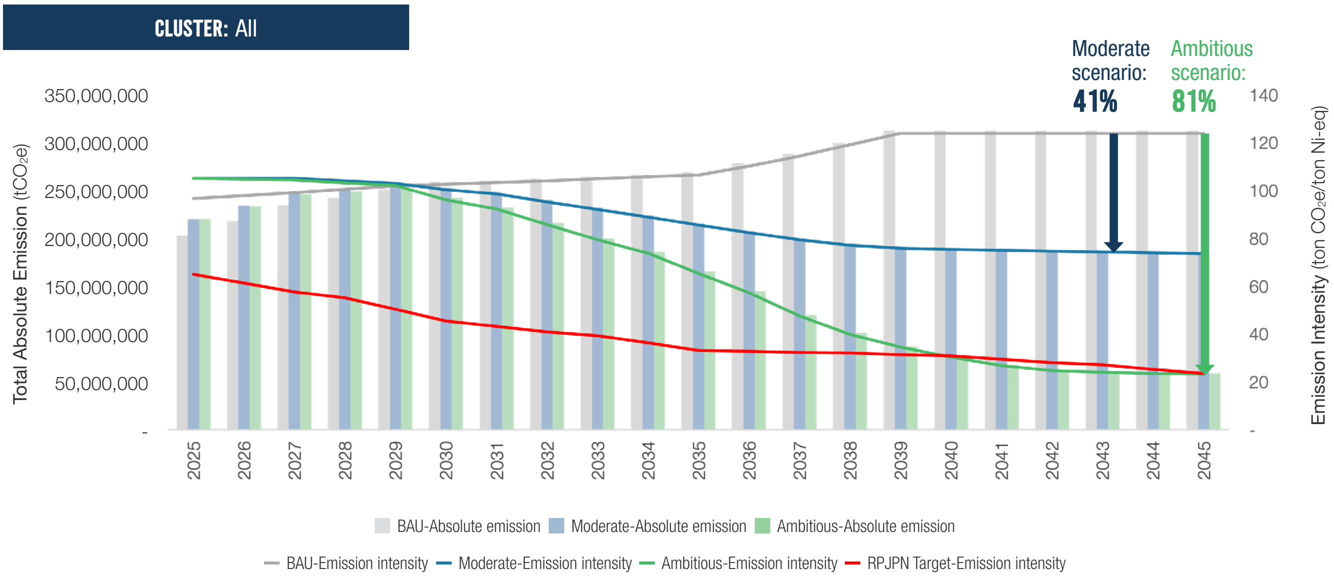
In the material substitution program, which involves setting a minimum threshold for average nickel content in ore inputs, both the Moderate and Ambitious scenarios share the same target. During the early years of the BaU modelling (until 2033), the average nickel content in ore is higher than in the Moderate and Ambitious scenarios. As a result, energy and material consumption per ton of product in the BaU scenario is initially lower. However, after 2033, regulated ore quality leads to a drop in energy and material intensity per ton of product in the decarbonization scenarios, making them more efficient than BaU.

For reductant material switching from coal to biomass, the Moderate Scenario limits coal replacement to 17% per company, based on the availability of palm kernel shell biomass in Indonesia. The Ambitious Scenario requires much higher replacement levels: up to 80% in Clusters 1 and 3, and 100% in Cluster 2 to achieve RPJPN emission reduction goals

In the low-carbon electricity program, all three clusters require significantly greater coal power replacement capacity under the Ambitious Scenario. The coal-based electricity mix drops from 96.1% to 4.1% by 2045, achievable through renewable energy sources such as solar, hydro, wind, and hydrogen. In the Moderate Scenario, renewable energy targets vary by cluster based on local availability. For example, Clusters 1 and 2 can only achieve 3.8% and 0.05% renewable energy mix, respectively, due to limited renewable resources near smelters and existing transmission infrastructure. Meanwhile, Cluster 3 can achieve a full 100% renewable energy mix.

These differing program capacities across the three scenarios result in varying absolute emissions and emission intensities. Under the Ambitious Scenario, average national emission intensity drops from 124.02 tCO_2e/t-Ni to 23.47 tCO_2e/t-Ni by 2050. In comparison, the Moderate Scenario achieves a reduction only to 73.00 tCO_2e/t-Ni, indicating a less substantial but still meaningful improvement over BaU conditions.

Figure 63.
Comparison of total absolute emissions and emission intensity of all scenarios to BaU conditions across clusters



SCENARIO		2025	2030	2035	2040	2045
Moderate	Percent Reduction	-8.7%	2.0%	18.7%	39.7%	41.1%
	Final Reduction Target Deviation	89.6%	78.9%	62.2%	41.2%	39.8%
Ambitious	Percent Reduction	-8.7%	6.3%	38.3%	75.2%	81.1%
	Final Reduction Target Deviation	89.6%	74.6%	42.6%	5.7%	-0.2%

At the national level, greenhouse gas emissions from nickel production via the pyrometallurgical route can be reduced by up to 81% under the Ambitious Scenario. In contrast, under the Moderate Scenario, national average emissions are reduced by only 41.2% compared to the BaU scenario. In other words, only the Ambitious Scenario is considered capable of meeting the emission reduction targets set out in the RPJPN 2025–2045. Under the Moderate Scenario, there remains 39.8% of emissions that still need to be reduced in order to meet RPJPN expectations.

Although the Moderate Scenario achieves a 41% emission reduction nationally, this reduction is largely driven by Cluster 3. This is due to differences in the availability of materials and energy across clusters, with Cluster 3 having significantly more renewable energy potential than the other two clusters.

In Cluster 1, the average emission intensity can only reach 85.15 tCO_2/t-Ni in 2045, in a Moderate Scenario. This value is equivalent to an emission reduction of up to 31% from the BaU scenario in the same year. However, when compared to the average emission intensity in 2023, the emission intensity of a Moderate Scenario is only able to reduce emissions by up to 9.81%. As a result of increasing production capacity, emission reductions in this Moderate Scenario are still not able to reduce absolute emissions in 2023. Where absolute emissions in the Moderate Scenario are still higher up to 27%. By increasing the target capacity for implementing Moderate Scenario programs to achieve Ambitious Scenarios, emission intensity in 2045 can reach 23.48 tCO_2e/t-Ni, equivalent to a decrease of up to 81.1% from the BaU scenario in the same year and 75.13% from the average emission intensity in 2023.

Figure 64.
Comparison of total absolute emissions and emission intensity of all scenarios to BaU conditions in Cluster 1

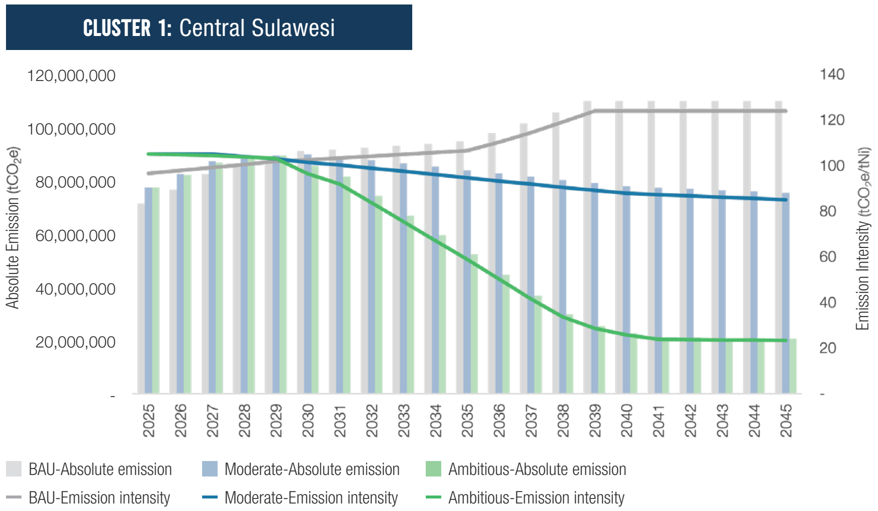
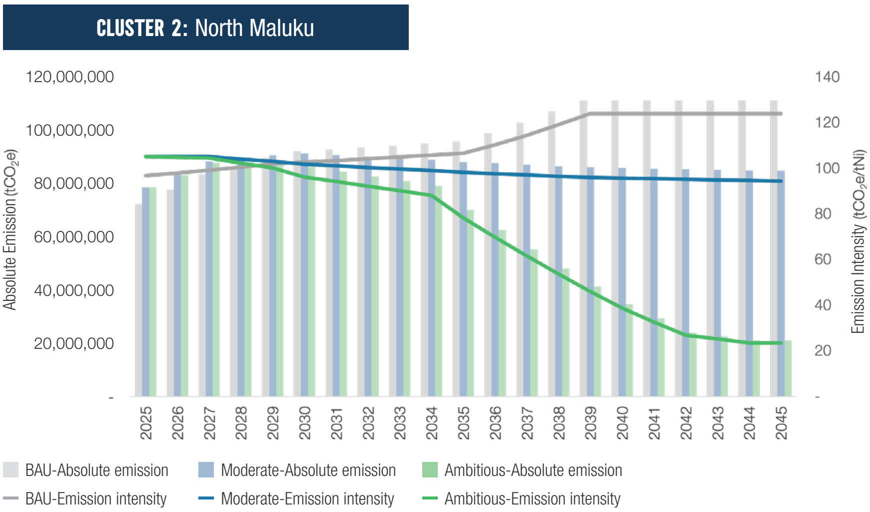


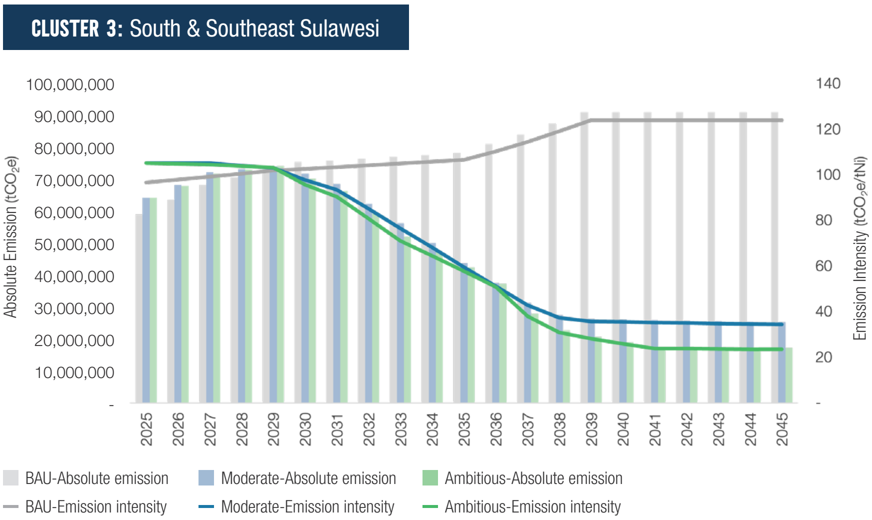
Figure 65.
Comparison of total absolute emissions and emission intensity of all scenarios to BaU conditions in Cluster 2



In Cluster 2 and Moderate Scenarios, the average emission intensity can only reach 94.46 tCO_2/t-Ni in 2045. This value is equivalent to an emission reduction of up to 24% from the BaU scenario in the same year. However, the Moderate Scenario has not been able to reduce emission intensity to lower than the emission intensity condition in 2023 due to a decrease in nickel metal content in ores. Furthermore, due to increased production capacity, total absolute emissions in the Moderate Scenario are still up to 40% higher than absolute emissions in 2023. However, by increasing the implementation capacity target to achieve an Ambitious Scenario, the emission intensity in 2045 can reach 23.45 tCO_2e/t-Ni, equivalent to a decrease of up to 81.1% from the BaU scenario in the same year and 75.17% from the average emission intensity in 2023.

In Cluster 3 Moderate Scenarios, the average emission intensity can reach 32.11 tCO_2/t-Ni in 2045. This value is equivalent to an emission reduction of up to 74.1% of the BaU scenario in the same year. When compared to the average emission intensity in 2023, the emission intensity of a Moderate Scenario is able to reduce emissions by up to 65.99%. By increasing the target of the implementation capacity of the Moderate Scenario program to achieve an Ambitious Scenario, the emission intensity in 2045 can reach 23.48 tCO_2e/t-Ni, equivalent to a decrease of up to 81.1% from the BaU scenario in the same year and 75.14% from the average emission intensity in 2023.

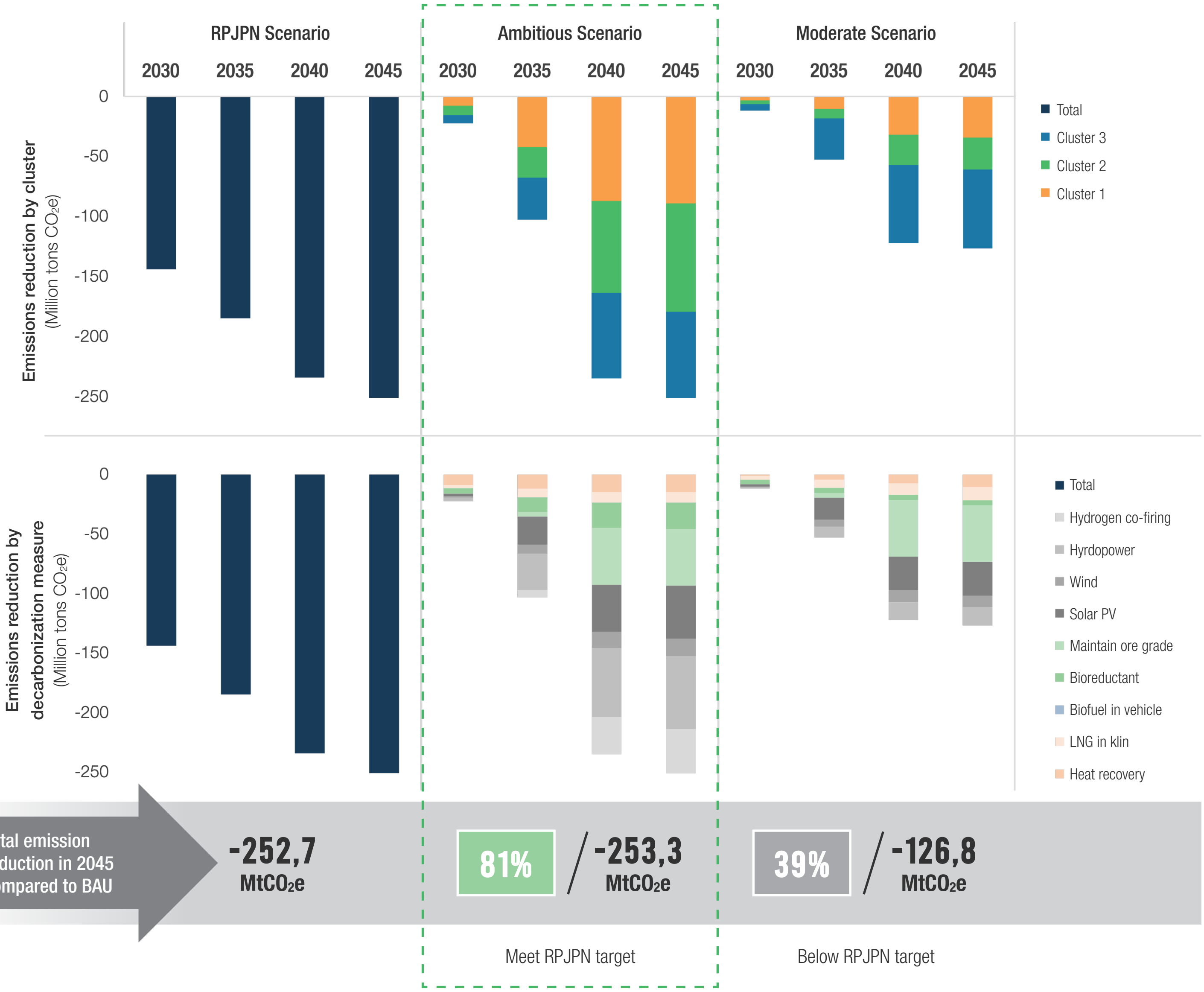
Figure 66.
Comparison of total absolute emissions and emission intensity of all scenarios to BaU conditions in Cluster 3



In other words, under the Moderate Scenario, only Cluster 3 is able to reduce its absolute annual emissions compared to 2023. The other two clusters succeed in lowering emission intensity relative to the BaU scenario in the same year, but are unable to offset the rise in absolute emissions driven by expanded production capacity.

Therefore, the scenario selected for follow-up is the Ambitious Scenario, which can achieve a total emission reduction of 253.3 million tCO_2e by 2045 compared to the total emissions under BaU conditions. This reduction is in line with, and even exceeds, the RPJPN target for the same year, which is 252.7 million tCO_2e (equivalent to an 80.98% reduction from BaU). The Ambitious Scenario achieves twice the emission reductions of the Moderate Scenario, which is limited to 126.8 million tCO_2e by 2045.

Figure 67.
Emission reduction results until 2045 in Ambitious and Moderate Scenarios



CHAPTER

05

POLICY RECOMMENDATIONS TO SUPPORT THE IMPLEMENTATION OF SELECTED DECARBONIZATION SCENARIOS

Referring to Chapter 4, the scenario chosen to be further implemented is the Ambitious Scenario , with a target of reducing industrial emissions by 81% by 2045. This scenario is projected to be able to reduce total emissions by 253.3 million tCO_2e from 2025 to 2045, in line with the emission reduction target in the RPJPN.

To realize this scenario, a transformation of the current nickel production ecosystem is needed. There are eight main policy directions (**Figure 68**) that will be implemented in 4 stages, namely:

Construction of the Transition Foundation
(2025–2029)

Basic Infrastructure Development and Early Phase Strategy Adoption
(2030–2034)

Adoption of Advanced Phase Strategy and Development Towards a Mature Market
(2035–2039)

Adoption of Optimal Phase Strategy and Achievement of Emission Reduction Targets
(2040–2045)

The form of transformation in the nickel industry supply chain after the policy is implemented is explained in **Figure 68**.

Figure 68.
Eight policy directions toward a low-carbon nickel industry in Indonesia (2025-2045)

Policy Directions for Realizing a Low-Carbon Nickel Industry in Indonesia (2025–2045)

Vision

The nickel industry in Indonesia will reduce GHG emissions by 81% by 2045

Mission

To ensure all facilities supporting the implementation of decarbonization strategy are available, accessible, affordable, with assured quality and safety

8

KEY POLICY DIRECTIONS FOR TRANSFORMING THE LOW-CARBON NICKEL INDUSTRY

1 Transition of electricity system

- **Revise the power generation and grid infrastructure plans** within the RUKN and the RUPTL to accommodate the decarbonization requirements of the nickel industry, while ensuring the seamless execution of these plans
- **Develop an attractive investment ecosystem** to finance power plant construction by implementing regulatory reforms, adjusting electricity tariffs, modifying contract durations, and providing guarantees aimed at mitigating project risk profiles
- **Reform and strengthen the Public-Private Partnership (PPP) mechanism for financing the construction of power plants and grid infrastructure** through improvements in mechanisms and mandates for financing infrastructure

2 Development of an integrated green hydrogen supply chain for clean electricity generation

- **Develop and implement a technical plan for building the green H_2 supply chain** — from hydrogen production, transportation, to clean power generation and distribution to smelters — while securing prospective buyers through off-take agreements
- **Provision of financing schemes and fiscal incentives for supply chain development** through PPP, guarantees, and import duty exemptions for key equipment such as electrolyzers and storage systems
- **Provide targeted subsidies for green H_2 and the clean electricity it generates**, to prevent severe negative margins in Cluster 2, using nickel royalties as a funding source
- **Establish technical and environmental standards for green H_2**

3 Development of Sustainable Biomass Supply Chain for Bioreductant Production

- **Establish technical and environmental standards for biomass and bioreductants,** including stricter enforcement of Energy Plantation Forests (HTE) implementation
- **Establish an attractive benchmark price for sustainable biomass**
- **Provide financing schemes and fiscal incentives for supply chain development** by optimizing private investment models, supported by guarantees and the use of a portion of revenue from palm kernel shell export levies to reduce CAPEX
- **Develop basic infrastructure for biomass supply chain development**, including a national strategy, action plan, KBLI code, regulations on recycling rates, and demand mapping

4 Expansion of Natural Gas Supply for Metallurgical Coal Substitution

- **Revise planning documents and regulatory frameworks supporting natural gas expansion**, including updates to the national gas balance and targets, alongside regulatory reforms to expedite the permitting process for gas terminals
- **Provision of financing schemes and fiscal incentives for the development of natural gas supply** infrastructure by optimizing private investment models, supported by the collection of off-take agreements, provision of guarantees, and import duty exemptions for key equipment such as regasification plants
- **Expansion of the HGBT regulation scope to also include the nickel industry**

5 Expansion of Energy Efficiency Adoption

- **Increase funding flows for energy efficiency projects** by mainstreaming the ESCO mechanism, establishing criteria within OJK's TKBI framework, and developing a catalog containing a list of accessible financing products
- **Development of technical guidelines and a best practice catalog** for the implementation of waste heat recovery in the nickel industry

6 Acceleration of Biodiesel Adoption in Indonesia

- **Monitor biodiesel market index prices** to prevent extreme fluctuations and price spikes
- **Establish environmental standards for biomass and biodiesel**
- **Ensure a reliable supply of biodiesel for the nickel industry** through off-take agreements
- **Update the national biodiesel blending targets for the post-2025 period**

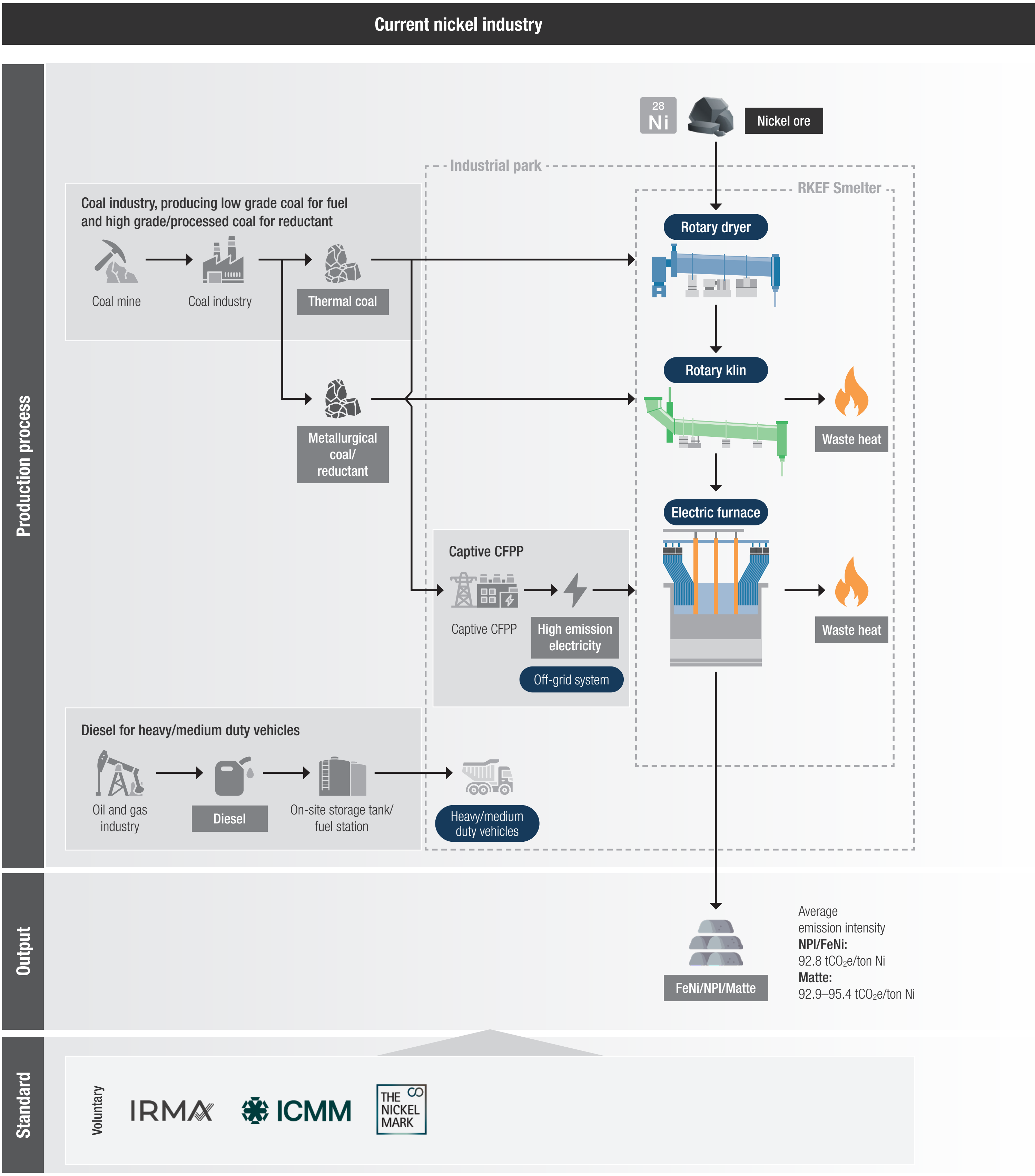
7 Improving national nickel decarbonization governance

- **Mandatory and gradual implementation of nickel industry decarbonization policies:**
  1. Nickel industries are required to report and reduce emissions (starting no later than 2029)
  2. Carbon trading in the power sector involving the nickel industry (starting no later than 2030)
  3. Carbon trading in the industrial sector involving the nickel industry (starting no later than 2034)
- **Develop a set of governance support instruments for decarbonizing the nickel industry,** such as:
  1. Guidelines for GHG emissions inventory in the nickel industry
  2. Emission reduction targets or performance standards for GHG mitigation efforts in the nickel industry (e.g., ministerial regulations or decrees on roadmaps, emission reporting systems specific to the nickel industry, or the 'Indonesian Green Nickel Standard')
  3. Market-based incentive mechanisms (e.g., carbon pricing)
  4. Non-market-based incentive mechanisms (e.g., fiscal and non-fiscal incentives from industrial estates)
- **Reform the governance system for nickel industry decarbonization** by integrating systems, reforming regulations and infrastructure, and improving inter-ministerial and institutional coordination models to enable more efficient impact assessments, target-setting, strategy formulation, reporting, and performance evaluation in support of achieving decarbonization goals

8 Implementation of nickel price control in the market

- **Establish a mechanism for controlling nickel supply** through:
  1. A moratorium on nickel smelter
- **Establish a mechanism to ensure demand availability for nickel** through:
  1. Development of domestic supply chains for stainless steel and high-grade nickel matte through downstream industrialization
  2. Establishment of emission standards for end products (e.g., buildings)
- **Ensure nickel prices remain stable and at a premium level through the following measures:**
  1. Establishment of the Indonesia Metal Exchange as the benchmark price setter for both conventional and green (premium) nickel
  2. Formation of a Nickel Logistics Agency (Bulog Nikel) or a SOE to manage production and export quotas, as well as to absorb FeNi & NPI for processing into high-grade nickel matte

Figure 69.
Transformation scheme for a low-carbon nickel industry



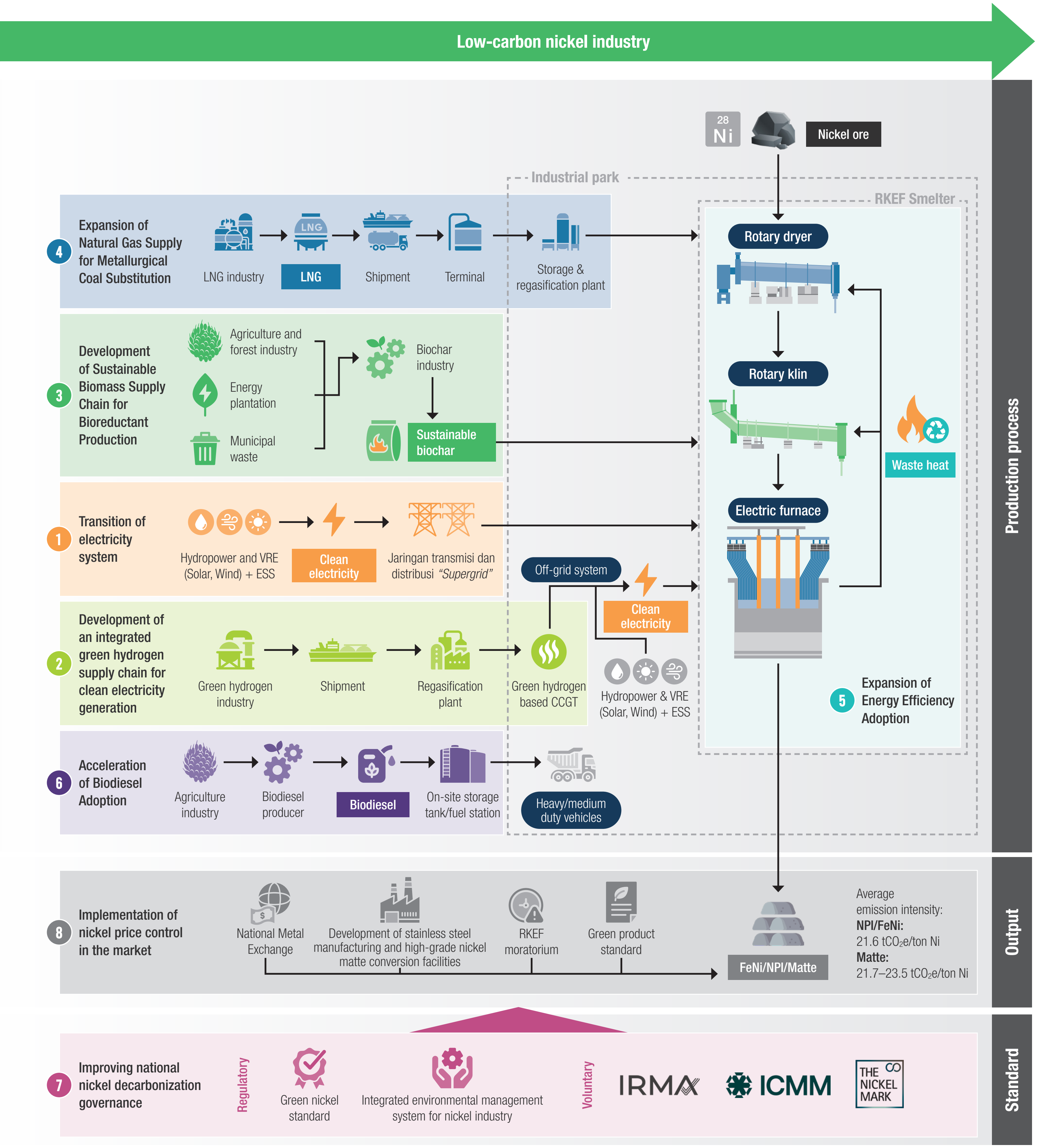

Low-carbon nickel industry
28 Ni
Nickel ore
Industrial park
RKEF Smelter
4 Expansion of Natural Gas Supply for Metallurgical Coal Substitution
LNG industry
LNG
Shipment
Terminal
Storage & regasification plant
Rotary dryer
3 Development of Sustainable Biomass Supply Chain for Bioreductant Production
Agriculture and forest industry
Energy plantation
Municipal waste
Biochar industry
Sustainable biochar
Rotary klin
Waste heat
1 Transition of electricity system
Hydropower and VRE (Solar, Wind) + ESS
Clean electricity
Jaringan transmisi dan distribusi *"Supergrid"*
Electric furnace
Off-grid system
Clean electricity
2 Development of an integrated green hydrogen supply chain for clean electricity generation
Green hydrogen industry
Shipment
Regasification plant
Green hydrogen based CCGT
Hydropower & VRE (Solar, Wind) + ESS
5 Expansion of Energy Efficiency Adoption
6 Acceleration of Biodiesel Adoption
Agriculture industry
Biodiesel producer
Biodiesel
On-site storage tank/fuel station
Heavy/medium duty vehicles
8 Implementation of nickel price control in the market
National Metal Exchange
Development of stainless steel manufacturing and high-grade nickel matte conversion facilities
RKEF moratorium
Green product standard
FeNi/NPI/Matte
Average emission intensity:
NPI/FeNi:
21.6 tCO₂e/ton Ni
Matte:
21.7–23.5 tCO₂e/ton Ni
7 Improving national nickel decarbonization governance
Regulatory
Green nickel standard
Integrated environmental management system for nickel industry
Voluntary
IRMA
ICMM
THE NICKEL MARK
Production process
Output
Standard

Figure 70.
Total energy, raw materials, and materials requirements for the decarbonization of the nickel industry 2025-2045

Green energy and material supply needed for decarbonization (2023–2045)

		2023	2030	2035	2040	2045
Hydro power (GW)	Cluster 1	0	0.13	1.3	2.4	2.5
	Cluster 2	0	~0	0.002	0.02	0.03
	Cluster 3	0	0.11	1.1	2.0	2.1
	Total	**0**	**0.24**	**2.4**	**4.4**	**4.6**
Wind power (GW)	Cluster 1	0	0.006	0.06	0.12	0.13
	+ H_2 production	0	0	0	0	0.002
	Cluster 2	0	0	0.002	0.02	0.03
	Cluster 3	0	0.7	6.9	13.1	13.2
	+ H_2 production	0	0	37.6	75.2	75.2
	Total	**0**	**0.7**	**44.6**	**88.4**	**88.5**
Solar power (GW)	Cluster 1	0	1.05	10.6	16.4	16.4
	+ H_2 production	0	0	7.9	15.8	15.8
	Cluster 2	0	0.007	0.87	5.0	8.4
	Cluster 3	0	0.74	4.4	4.4	4.4
	+ H_2 production	0	0	28.2	56.3	56.3
	Total	**0**	**1.8**	**51.9**	**97.9**	**101.3**
Green hydrogen based CCGT (GW)	Cluster 1	0	0	0	0	0
	Cluster 2	0	0	0.75	4.7	5.1
	Cluster 3	0	0	0	0	0
	Total	**0**	**0**	**0,75**	**4,67**	**5,1**
LNG (million tons)	Cluster 1	0	0.2	0.6	1.0	1.0
	Cluster 2	0	1.4	3.5	4.1	4.1
	Cluster 3	0	0.2	0.6	0.8	0.8
	Total	**0**	**1.8**	**4.7**	**5.9**	**5.9**
Bioreductant (million tons)	Cluster 1	0	0.4	1.2	2.9	3.1
	Cluster 2	0	1.2	3.1	3.9	3.9
	Cluster 3	0	0.3	1	2.4	2.6
	Total	**0**	**1.9**	**5.3**	**9.2**	**9.6**
Biodiesel (million litres)	Cluster 1	96.8	155.1	193.9	232.7	271.5
	Cluster 2	97.9	156.9	196.1	235.3	274.5
	Cluster 3	80.1	128.4	160.5	192.6	224.7
	Total	**274.8**	**440.4**	**550.5**	**660.6**	**770.7**

Figure 71.
Total funding needs for the decarbonization of the nickel industry 2025-2045

Decarbonization Strategy	Capital Cost (CAPEX) (million $)	Operating Cost (OPEX) (million $)	Energy/ material Cost (million $)	Total Additional Cost (million $)	Levelized Cost of Carbon (LCC) ($/tCO$_2$e)	Coverage of Cost Components in the Model	
						Included	Not included
Hydro power	166.9	-9.5	-120.7	14.4	8.86	• Power plant construction cost • Battery storage purchase cost • On-grid electricity purchase cost	On-grid transmission line construction cost
Wind power	29.3	-5.4	-9.6	14.4	45.34		
Solar power + BESS	11,700	-939.7	-4,380	6,379	42.46		
Green hydrogen based CCGT	9,799	-2,097	8,141	15,843	31.75	• Green hydrogen purchase cost • Power plant construction cost	• Green hydrogen production and infrastructure cost (incl: electrolyzer) • Off-grid transmission line construction cost
LNG	4,258	5,191	15,381	24,829	149.37	• LNG purchase cost • Regasification plant construction cost	LNG production and infrastructure cost (incl: terminal)
Bioreductant	-	-	4,952	4,952	13.66	Bioreductant purchase cost	Bioreductant production cost
Biodiesel	-	-	354	354	378.81	Biodiesel purchase cost	Biodiesel production and infrastructure cost
Maintain ore grade	-	-	6,545	6,546	12.93	Nickel ore purchase cost	Nickel ore screening/ sorting activity cost
Energy efficiency	5,447	4,214	-8,352	1,309	4.57	Equipment adjustment/ modification cost at plant (retrofitting)	
Total	**31,400**	**-32,041**	**94,908**	**94,267**	**25.39**		

Figure 72.
Capital cost required to implement the decarbonization strategy in the nickel industry until 2045 (CAPEX)
Million USD

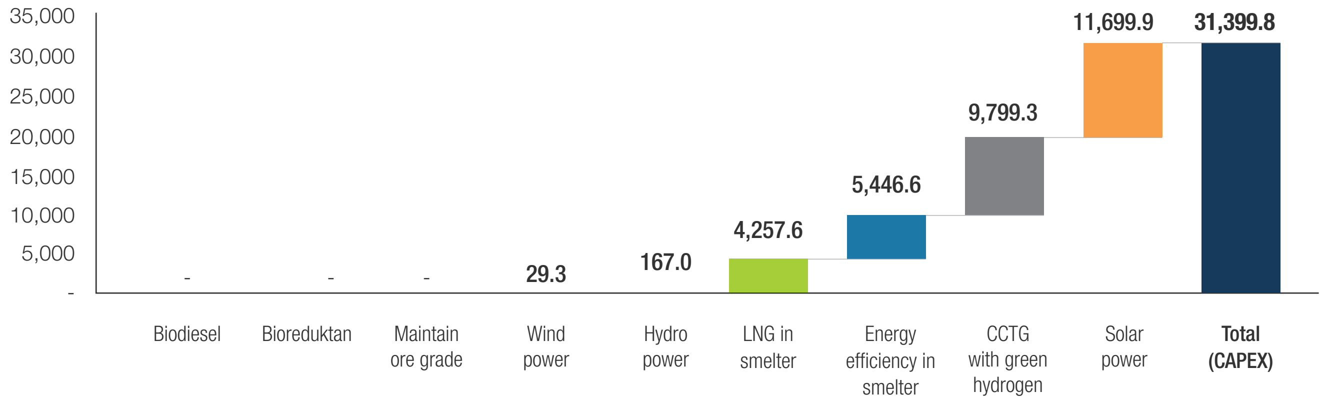


Figure 73.
Recommended funding strategies for the decarbonization of the nickel industry 2025-2045

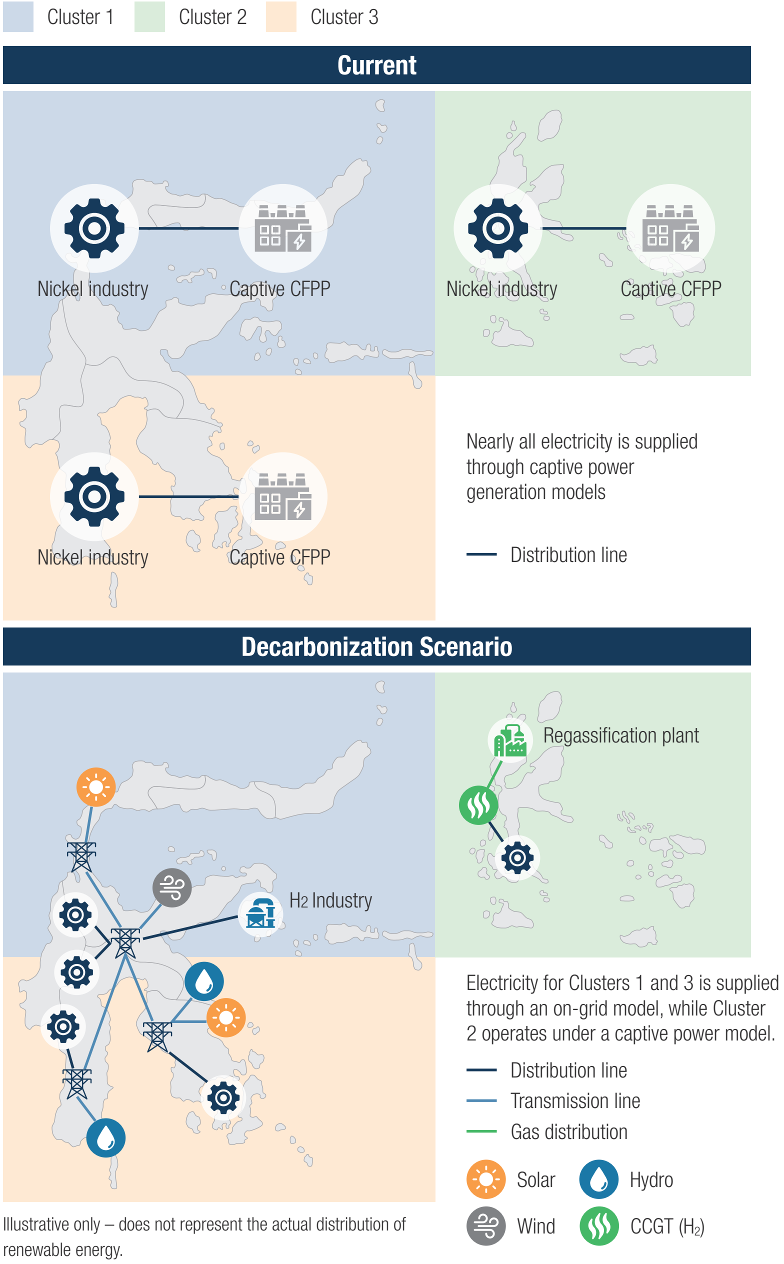
Decarbonization Strategy	Financing Component	Project Owner/ Responsible Party	Financing Scheme	Funding Source	Enabler				
					Price Correction	Project Submission and Inclusion in PPP Plan	Provision of Financing Guarantee	Regulatory Reform	Incentives
Transition of electricity system	Construction of new renewable power plants (hydropower, solar PV, wind)	Independent Power Producer (IPP)	Private investment	Commercial loan	Correction of reference price for renewable electricity to improve investment attractiveness for PLN and IPPs, as regulated under Presidential Regulation No. 112/2022		Provided by PT PII as the project is strategic for the energy transition and supports the fulfilment of the Electricity Supply Business Plan (RUPTL)	Revision of regulations to improve investment climate for renewable power projects, including: • Extension of Power Purchase Agreement (PPA) periods (to reduce project risk) • Streamlining environmental and land permit processes	
		PT PLN Persero	Public–Private Partnership (PPP)	Blended financing		Proposed for grid construction projects in Sulawesi and North Maluku	Provided by PT PII, as strategic for energy transition and low project IRR		
	Construction and modernization of power transmission and distribution networks	PT PLN Persero	Public–Private Partnership (PPP)	Blended financing					
Development of an integrated green hydrogen supply chain for clean electricity generation	Construction of green hydrogen production facilities	PT PLN Persero	Public–Private Partnership (PPP)	Blended financing	Subsidy for green hydrogen prices, specifically for nickel industry operations in North Maluku	Proposed for hydrogen industry construction projects in Sulawesi	Provided by PT PII as strategic for energy transition and low project profitability		Exemption of import duties for key technology components (e.g., electrolyzers, storage systems, and gas turbines)
	Construction of captive gas turbine power plants (CCGT) and supporting infrastructure	Nickel company/ industrial park developer	Private investment	Blended financing	Adjustment of green electricity prices and impacts on hydrogen subsidy prices	Proposed for hydrogen-based captive PLTGUs and hydrogen distribution networks for nickel industry operations in North Maluku			
Development of Sustainable Biomass Supply Chain for Bioreductant Production	Construction of bioreductant production facilities	Private sector (e.g., PLN EPI, etc.)	Private investment	Commercial loan	Adjustment of domestic biomass prices to be competitive with export market using reference price (HBmA)		Provided by PT PII as strategic for energy transition but not yet prioritized by development banks due to limited transition finance options for biomass		Study on optimizing the use of palm oil export levy funds (BPDP) to subsidize sustainable biomass supply chain development
Expansion of Natural Gas Supply for Metallurgical Coal Substitution	Expansion of LNG industry capacity and construction of LNG distribution infrastructure	Private sector (e.g., Medco, Inpex, Pertamina, Shell)	Private investment	Blended financing	Coverage expansion of HGBT (fixed natural gas price for industry), including the nickel sector		Provided by non-bank financial institutions acting as de-risking partners, given high project profitability		
	Construction of regasification plants	Nickel company/ industrial park developer	Private investment	Commercial loan				Fast-tracking the addendum process for special terminal (*tarsus*) licensing	Import duty exemption for key technologies (e.g., regasification plants)
Expansion of Energy Efficiency Adoption	Smelter retrofit and implementation of waste heat recovery systems	Nickel company	ESCO	Commercial loan				Establishment of energy efficiency criteria within a green taxonomy framework comparable to those of other countries	Research incentives for domestic manufacturers of high-efficiency energy technologies
Acceleration of Biodiesel Adoption in Indonesia	Biodiesel production	PT Pertamina Persero	Private investment	Commercial loan	Implementation of a study to develop a strategy for managing biodiesel price increases for the industry in line with the progressive rise in blending targets				Continuation of biodiesel production subsidies through BPDP

5.1

NICKEL INDUSTRIAL TRANSITION OF ELECTRICITY SYSTEM

The largest source of emissions from the nickel industry comes from power generation with a contribution of 63.5% of the total emissions in the smelter. This is due to the dominant use of captive coal power plants due to the limited coverage of the on-grid electricity system around the nickel smelter area.

Figure 74.
Illustration of changes in electricity supply schemes to implement decarbonization scenarios



Nearly all electricity is supplied through captive power generation models

Electricity for Clusters 1 and 3 is supplied through an on-grid model, while Cluster 2 operates under a captive power model.

Illustrative only – does not represent the actual distribution of renewable energy.

To reduce emissions, a gradual transition from coal-fired power plants to renewable energy sources is needed. Key elements for implementing this strategy include ensuring that renewable energy sources are available to meet smelters' net electricity needs (availability), that clean electricity is delivered through an expansive, modern, and reliable grid (accessibility), and that clean electricity is priced affordably (affordability).

Regarding the availability aspect, there is a gap in the potential for renewable energy (solar, wind, and hydro) between Clusters 1 and 3 and Cluster 2. Clusters 1 and 3 have abundant potential, so they will optimize clean electricity consumption from these sources. Meanwhile, Cluster 2 has very limited potential for the same energy, making green hydrogen the main alternative (discussed in Section 5.2). The total electrical energy requirements from conventional renewable energy sources for the nickel industry in 2025-2045 are described in **Figure 70**.

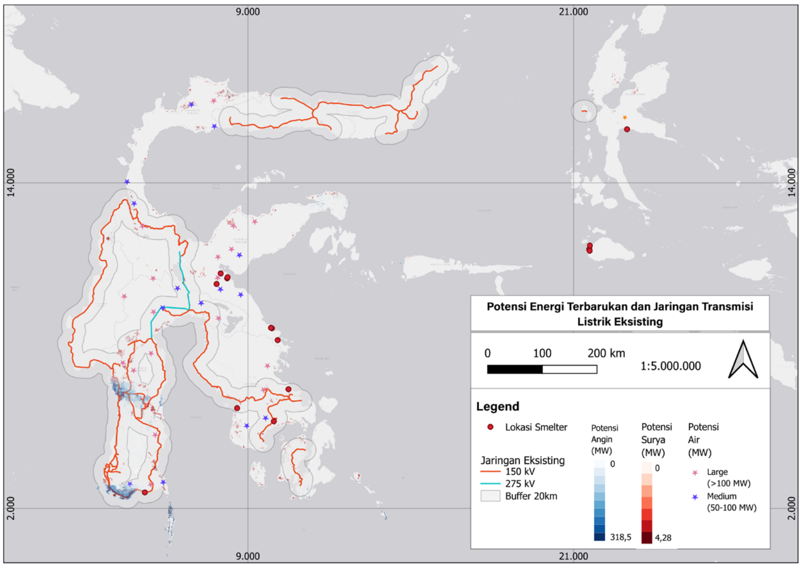
Although the potential for clean electricity is sufficient, the limited coverage of the electricity grid is often the cause of this potential not being utilized optimally. So, to ensure accessibility, this roadmap recommends an on-grid electricity supply model for the nickel industry in Clusters 1 and 3 in Sulawesi, while the model for Cluster 2 (North Maluku) is off-grid.

In the on-grid model, it is necessary to expand PLN's transmission and distribution network in Sulawesi which is connected to the nickel industry in Clusters 1 and 3. In the off-grid model, the development of transmission and distribution systems is also needed but on a more limited scale and carried out by the private sector.

The selection of the electricity supply model is in line with the RUKN 2025-2060 which plans to significantly expand the electricity transmission network in Sulawesi. In Sulawesi, RUKN plans to develop a supergrid backbone transmission network that will support interconnection within the island and between islands. For the internal interconnection of the Sulawesi islands, the Sulbagut-Sulbagsel network will be developed, while for the inter-island Sulawesi will be connected with Kalimantan in 2041 and with Sumbawa in 2045. The 2025–2034 RUPTL also sets out a transmission development plan for Sulawesi, covering Morowali, North Morowali, Konawe, North Konawe, and Kolaka—key centers of nickel production and downstream industries. Beyond connecting smelter areas, the plan also aims to link potential renewable energy sources, particularly in eastern Central Sulawesi (Banggai Regency and surrounding areas) and the northern region (Buol Regency and surrounding areas), as shown in **Figure 75**. If the potential of new and renewable energy (EBT) within a radius of 20 kilometres along the transmission network listed in the RUPTL and RUKN is optimally utilized, it could meet nearly all of the decarbonization needs under the Ambitious Scenario.

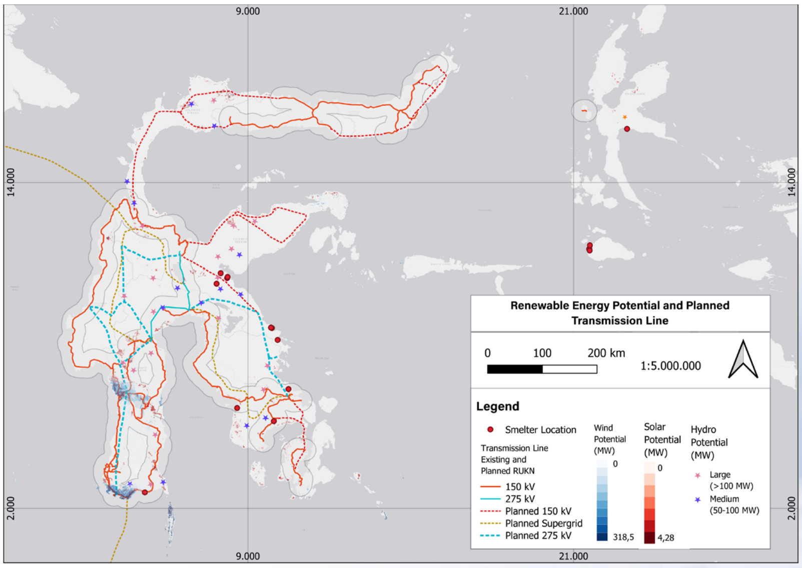
Figure 75.
Comparison of the configuration and potential coverage of the current transmission network (above) and plan (below)

Saat Ini



% RE within 20 km from grids	Solar	Wind	Hydro
Cluster 1 (Central Sulawesi)	12.2%	5.4%	3.5%
Cluster 2 (North Maluku)	0.7%	16.5%	NA
Cluster 3 (South & Southeast Sulawesi)	29.6%	83.2%	58.1%

Rencana



% RE within 20 km from grids	Solar	Wind	Hydro
Cluster 1 (Central Sulawesi)	75.3%	35.8%	72.9%
Cluster 2 (North Maluku)	0.8%	16.5%	NA
Cluster 3 (South & Southeast Sulawesi)	29.6%	84.8%	67.0%

renewable energy output depends on weather and time, there is variability and uncertainty due to mismatches between the amount of production and the time of electricity demand in real time. To address this, the grid also needs to be equipped with energy storage systems, such as large-scale batteries (BESS) and Pumped Hydro Energy Storage (PHES), so that surplus energy can be stored and used when needed.

While this policy direction is generally aligned with the RUKN 2025–2060 and RUPTL 2025–2034, several differences remain and form the basis of further policy recommendations for implementing this roadmap, including:

- According to the RUPTL, the solar power capacity planned through 2034 remains below the requirements of the Ambitious Decarbonization Scenario, whereas wind and hydropower capacity already meets the target—although this figure reflects total capacity across all sectors. In the longer term, the RUKN projects lower solar, wind, and hydropower capacity than what is required under the Ambitious Scenario. This gap arises because the Ambitious Scenario assumes an accelerated build-out of renewable energy beginning in 2035 (see **Table 6**).
- The realization of all renewable energy potential along existing transmission network lines and plans have not met the overall decarbonization needs of the nickel industry, so further network expansion is needed (see **Table 6**).
- Providing clean electricity to nickel smelters through the integration of transmission network expansion plans and the development of EBT infrastructure to the nickel industry that still uses a captive/off-grid model.

Therefore, it is necessary to update the planning in the RUKN and RUPTL to implement this roadmap optimally. The alignment of the planning document is important in supporting the financing of the decarbonization of the nickel industry, considering that several funding mechanisms, such as the Energy Transition Mechanism (ETM), require renewable energy plant construction projects and new power networks to be listed in the RUPTL to be able to obtain such funding facilities. The recommendations for the form of renewal are as follows.

Table 6.
Recommendations for updating the clean electricity generation plan in the RUKN 2024-2060 and the RUPTL for the next period (2035-2044)

Cluster[1]	Energy sources	EBT power generation capacity in 2034 (GW)		EBT power generation capacity in 2045 (GW)		Recommendations for RUKN (2025-2060) and the next RUPTL (2035-2044)[2]
		The decarbonization needs of the nickel industry	RUPTL 2025-2034 (all of them)	The decarbonization needs of the nickel industry	RUKN 2025-2060 (all of them)	
1 (Central Sulawesi) and **3** (South and Southeast Sulawesi)	Solar	1.79	1.53	20.39	6.0	Generating all renewable energy potential along the transmission network in RUPTL and RUKN (47.01 GW) to meet the decarbonization needs of industry (20.39 GW) and other sectors.
	Wind	0.70	1.01	13.95	6.6	• Generate all renewable energy potential along existing transmission networks and plans in RUPTL and RUKN (11.78 GW) • Further expansion of transmission network to add 2.17 GW of power generation
	Hydro	0.23	4.6	4.64	6.9	• Generating all renewable energy potential along existing transmission networks and plans in RUPTL and RUKN (3.26 GW) • Further expansion of the transmission network to add 1.39 GW of power generation
2 (North Maluku)	Solar	0.007	1.47	8.38	66.4	Build a clean electricity supply system with a captive/off-grid model
	Wind	0	0.14	0.027	8.6	
	Hydro	~0	0.179	0.027	2.1	

Finally, with regard to affordability, the sharp increase in demand for clean electricity in the nickel industry must be matched by the development of adequate new power infrastructure. This makes the availability of a clear financing strategy essential. For Clusters 1 and 3, considering that the electricity financing model is targeted to transform into on-grid, PLN will serve as the main entity responsible for development. As for Cluster 2, the financing is carried out entirely by the nickel industry considering that the infrastructure built is off-grid.

In general, there are two main components that require financing, namely power plant construction and power grid construction. For the construction of power plants, it is projected that 81.3 billion USD will be needed to meet the needs of clean electricity according to the Ambitious

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[1] In RUKN and RUPTL, Clusters 1 and 3 are combined as one same service area, namely "Sulawesi". Meanwhile, Cluster 2 is combined with several other regions outside the scope of the road map, namely "Maluku, Nusa Tenggara, and Papua". The writing of the table follows the categorization of RUKN and RUPTL so that Clusters 1 and 3 are merged and Cluster 2 stands alone.

[2] The figures in this recommendation are derived from the results of modelling to achieve the Ambitious Scenario targets in this roadmap.

Scenario of this roadmap. To realize this, a large contribution from the private sector is needed. In the 2025–2034 RUPTL, the Ministry of Energy and Mineral Resources has allocated 73 percent participation space to private power producers (Independent Power Producers / IPPs) for the construction of power plants. Meanwhile, for the construction of the transmission network, the most appropriate financing scheme is through Government and Business Entity Cooperation (PPP), considering that the rate of return on investment (IRR) on power grid projects is relatively low.

However, there are three main challenges that hinder the implementation of the above financing strategy, including: (1) The investment climate is less attractive for investors; (2) High interest rates for commercial projects; and (3) Lack of optimal implementation of innovative financing in the electricity sector.

First, an unattractive investment climate for investors arises due to four main factors: uncompetitive electricity tariffs, overly restrictive and protectionist local content (TKDN) regulations, lengthy land permitting processes, and issues related to extortion and land price mark-ups. The government, through Presidential Regulation No. 112 of 2022, replaced the feed-in tariff scheme with a ceiling price mechanism (maximum benchmark price for electricity purchases). However, this policy requires the actual electricity purchase price to be determined through negotiation and bidding processes, which in turn extends project development timelines from an average of 7 years to 10–12 years. During negotiations, the main focus tends to be on achieving the lowest purchase price, which often proves unfavourable for IPPs. In fact, based on calculations in this study, even using the ceiling price results in negative margins for IPPs, ranging from -$0.15/kWh to -$4.43/kWh depending on the energy source.

On the other hand, Indonesia had previously implemented TKDN requirements for electricity infrastructure development projects, which led to the stagnation of eight foreign funding projects worth Rp51.5 trillion, including the construction project of a 275 kV transmission network along 830 kilometres of circuits (kms) with a COD target by 2027. However, in mid-2024, three new regulations on TKDN relaxation have been issued, one of which is Minister of Energy and Mineral Resources Regulation No. 11 of 2024 which imposes an exemption from TKDN requirements specifically for electricity infrastructure development projects with a minimum funding of 50% from development funds (both loans and grants). This new regulation is expected to remove the past impression of prospective lenders on electricity investment opportunities in Indonesia.

Regarding the lengthy land permitting process, this is primarily caused by the Environmental Impact Assessment (EIA) process and the issuance of land suitability permits. The EIA process tends to take time due to the absence of best practice guidelines for assessing the environmental impacts of power generation and transmission projects. As a result, the level of scrutiny varies between projects depending on the standards of each assessor. Meanwhile, the issuance of land suitability permits is prolonged because clean power projects do not have designated development zones from the outset, forcing the government to conduct a series of studies to assess current land conditions and consider alternatives in the case of land-use conflicts.

There are two main solutions proposed to create a more attractive investment climate for renewable energy–based power system development: (1) adjusting the ceiling price for electricity purchases, and (2) providing legal certainty over regulations affecting the permitting process for construction projects. Adjusting the benchmark electricity price paid by PLN to IPPs will have a downstream impact on the electricity price PLN charges to the nickel industry. Recommended price adjustments are presented in Tables 7 and 8. These adjustments are aimed at securing a minimum profit margin of 5 percent for both PLN and IPPs, while maintaining at least a 10 percent margin for the nickel industry as the end consumer. As for legal certainty, the government is expected to act in three ways. First, by developing EIA guidelines for power projects to standardize analytical components, measurement methods, and environmental mitigation based on best practices. Second, by designating specific development zones for clean power projects in the RTRW as a derivative of the RUPTL. Third, by setting an upper limit for land prices to reduce extortion and land speculation practices.

Table 7.
Recommended highest benchmark price for electricity purchase from IPP by PLN

Clean power source	Cluster	Generating Capacity	**PLN purchase price** (cents USD/kWh)				LCOE Model
			Before*		Recommendations		
			Years 1-10	Years 11-30	Years 1-10	Years 11-25	
Hydro	1	20–50 MW	9.746	5.54	5.35 ↓	3.041 ↓	4.31
	2	20–50 MW	11.075	5.54	6.15 ↓	3.496 ↓	5.39
	3	20–50 MW	9.746	5.54	5.35 ↓	3.040 ↓	4.31
Wind	1	>20 MW	10.494	5.73	13.7 ↑	7.493 ↑	10.95
	2	>20 MW	11.925	5.73	14.9 ↑	8.190 ↑	13.1
	3	>20 MW	10.494	5.73	13.7 ↑	7.495 ↑	10.96
Solar (Photovoltaic)	1	>20 MW	7.645	4.17	13.3 ↑	13.677 ↑	10.36
	2	>20 MW	8.6875	4.17	12.9 ↑	7.069 ↑	11.3
	3	>20 MW	7.645	4.17	13.6 ↑	7.396 ↑	10.1

**) Source: Presidential Regulation No. 112 of 2022*

Table 8.
Recommended tariff of PLN electricity sales to industry

Cluster	**PLN's electricity sales price to industry** (IDR/kWh)	
	Before	Recommendations
1 and 3	996.74	1,139.8 ↑

The second challenge in financing electricity infrastructure is the high interest rate for commercial electricity projects (such as the construction of renewable energy plants). Currently, the average interest rate of banks in Indonesia is 6.25%, higher than a number of developed countries[3]. In the eyes of banks, the risk profile of clean power plant development projects in Indonesia is quite high because the average period of electricity purchase and sale contracts between IPPs and PLN and industry ranges from 1-5 years. This duration is very short when compared to the projection of a new payback of the plant that was achieved after ~20 years.

To overcome this, the risk profile of power plant development projects must be lowered. This can be done by extending the power purchase and purchase contract period to 20 years and providing guarantees from the government through PT PII considering that this infrastructure is crucial for the energy transition. On the one hand, Bank Indonesia through PBI No. 24/3/PBI/2022 has required banks to allocate 30% of their financing portfolios to industries that have been determined by Bank Indonesia, including through ESG-related financing. The government needs to provide incentives for banks' compliance with the PBI. It is hoped that this combination of enabling conditions can finally motivate banks to lower interest rates and increase the amount of green funding launched into the market.

The third challenge in financing electricity infrastructure is the lack of optimal implementation of the PPP mechanism and innovative funding in financing non-commercial electricity projects (such as power grid construction and early retirement of coal-fired power plants). Indonesia already has several innovative

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[3] OliverWyman, 2024

funding mechanisms such as PT SMI (which accommodates ETM) and JETP. However, until now, the electricity project portfolios of the two agencies are still very minimal and have not even financed the construction of the power grid or the early retirement of coal-fired power plants at all. The electricity projects financed by PT SMI are only 52 EBT power plant construction projects with a total capacity of >2 GW[4]. Meanwhile, the electricity project financed by JETP is only for the construction of solar power plants in Java and solar power plants in Sumatra with a total generation capacity of 0.23 GW. [5]The amount is still very small when compared to the needs of the national nickel industry alone.

By necessity, blended financing is a key strategy to finance projects that are important to the public but have low profits and high risks. Commercial projects have alternatives such as commercial loans, but not with non-commercial projects. Therefore, innovative financing mechanisms should be prioritized for the financing of such non-commercial projects. There are at least two key reasons for the suboptimal use of innovative financing in supporting industrial decarbonization in Indonesia. First, industrial decarbonization projects are not sufficiently covered in the PPP Priority Project List of the Ministry of National Development Planning/ Bappenas. Second, PT SMI—along with its financing instruments such as the ETM—has not been given a strong mandate to finance non-commercial decarbonization projects, resulting in commercial projects also being included in its financing portfolio.

To address these issues, two solutions are proposed. The first solution involves updating the List of National Priority PPP Projects for 2025 (and beyond) to align with the vision of industrial decarbonization. The second solution focuses on improving the financing framework for non-commercial industrial decarbonization projects in Indonesia.

For the first solution, all electricity grid construction projects and selected power plant projects in Sulawesi that are not financed by Independent Power Producers (IPPs) should be included in the list of National Priority PPP Projects issued by the Ministry of National Development Planning (Bappenas). In addition, other decarbonization projects related to the nickel industry—such as the development of green hydrogen supply chains—that are recommended to be financed through PPP schemes should also be included. This list should then be submitted to PT SMI and other financing platforms (such as the ETM, Danantara, and IIF) to serve as a reference for funding priorities and to facilitate progress monitoring. Moreover, the list can be forwarded to the Ministry of Finance as a reference for providing subsidies and compensation. With the availability of such a priority project list, it is expected that the financing activities of PT SMI and other platforms will become more targeted and effective.

Regarding the second solution, financing for decarbonization projects requires a clear and robust risk structure to ensure proportional and effective risk-sharing among non-bank financial institutions, private banks, and public agencies. To address this need, a blended financing guideline should be issued as a form of soft infrastructure to guide the structuring and financing of such projects.

Furthermore, to address the medium-long term financing gap faced by high-risk and public-oriented decarbonization projects, Indonesia must have a funding platform with a specific and explicit mandate to support the transformation of a low-carbon economy through the financing of industrial decarbonization support projects, especially non-commercial ones. This mandate can be given either to PT SMI or expand the mandate of the ETM, or it can be realized by supporting the discourse on the establishment of a national green financial institution (National Green Development Bank) to take over financing in this regard considering that PT SMI has a variety of funding priorities outside of the aspects of decarbonization and the green economy such as housing, transportation, and telecommunications. Indonesia can build and study the business models of other countries' National Development Bank such as Germany's KfW, and India's IIFCL can be a breath of fresh air for financing non-commercial decarbonization projects.

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[4] PT SMI presentation material (May 2025)

[5] https://portfolio.jetp-id.org/project/muara-laboh-geothermal-power-plant per Juni 2025

Table 9.
Policy framework to accelerate the transition of electricity system in the nickel industry 2025-2045

Policy Directions	Transition of electricity system
Objective	Clean electricity for the decarbonization needs of the nickel industry is available, accessible, and affordable

Challenge	Action Plan	Measure of Success	Milestone					Lead agency	Other related parties
			2025–2029		2030–2034	2035–2039	2040–2045		
The plan to increase clean power generation capacity and expand the national power grid has not been able to meet the decarbonization needs of the nickel industry	Alignmentof national electricity planning documents	The construction targets of power plants and electricity supply networks in Sulawesi and Maluku in the RUKN and RUPTL are updated and implemented	Determination of electricity supply models for each cluster and determination of the construction portion of off-grid and on-grid power plants	Alignment of power plant construction targets in RUKN 2024-2060 and RUPTL	2.74 GW of clean electricity available -0.23 GW of hydropower -0.7 GW of solar power -1.81 GW of solar power	25.18 GW of clean electricity available -2.33 GW of hydropower -7.02 GW of hydropower -15.83 GW of solar power	47.3 GW of clean electricity available -4.67 GW of hydropower -13.31 GW of solar power -29.32 GW of solar power	Ministry of Energy and Mineral Resources	PLN, IPP, nickel industry
				Alignment of the electricity grid expansion and modernization targets in the RUKN 2024-2060 and RUPTL	Power grid expansion reaches 1.5% increase in renewable energy demand	Electricity grid expansion reaches 23% increase in renewable energy demand	Power grid expansion reaches 91% increase in renewable energy needs		PLN
						Injection of 15.83 GW of batteries into the power grid	Injection of 29.32 GW of batteries into the power grid		
The investment climate for power generation projects remains unattractive due to low electricity tariffs, lengthy land acquisition and permitting processes, as well as issues of extortion and land price mark-ups	Development of an attractive investment climate for financing the construction of power plants (1/2)	Regulatory reform to facilitate and accelerate the construction of clean electricity projects	The preparation of an evaluation study on the administrative mechanism for the development of construction projects for power plants and clean electricity networks	Determination of special development areas for power plant and clean power grid construction projects within the National RTRW	Implementing a ceiling price for land acquisition is necessary to curb extortion and reduce irregularities during the land procurement process			Ministry of Energy and Mineral Resources	Ministry of ATR-BPN, Local Government
				Issuance of technical guidelines for environmental impact analysis of electricity projects to standardize analysis components, impact measurement methods, and environmental impact mitigation measures in accordance with best practices (using the EIA format)					Ministry of Environment
		Adjustment of net electricity purchase and sale prices to ensure mutual benefit for industry, IPPs, and PLN	Amendment of Presidential Regulation 112 2022 to change the highest benchmark price for the purchase of on-grid clean electricity from IPPs by PLN		The purchase price of on-grid net electricity from IPPs by PLN follows a more attractive recommended price because it can bring a profit of 5% for IPPs, 5% for PLN, but still maintain a 10–15% margin for the industry				PLN
					The selling price of on-grid net electricity from PLN to the industry follows a more attractive recommended price because it can bring a profit of 5% for IPPs, 5% for PLN, but still maintain a 10–15% margin for industry				

Challenge	Action Plan	Measure of Success	Milestone					Lead agency	Other related parties
					2030–2034	2035–2039	2040–2045		
Interest rates for commercial electricity projects (e.g. power plant construction) are higher than the developed country average (6.25%)	Development of an attractive investment climate for financing the construction of power plants (2/2)	Risk profile of power plant projects reduced, enabling banks to lower lending rates to 5%	Extending the duration of Power Purchase Agreements (PPAs) between IPPs and PLN, as well as between PLN and industrial consumers, to reduce project risk and enhance financial institutions' confidence, thereby enabling lower lending interest rates		Providing incentives for banks that allocate 30% of their banking portfolio for green credit in accordance with PBI No. 24/3/PBI/2022			Ministry of Energy and Mineral Resources	PLN, IPP
			Provision of guarantees for power plant construction projects in Sulawesi and North Maluku by PT PII					Ministry of Finance, Bank Indonesia	PT PII, Financial Institutions, JETP
	PPP optimization for network construction and power plant financing	Power plant construction projects are designated as PPP and receive funding	Power plant projects in Sulawesi included in the national PPP list published by Bappenas	Distribution of funds by existing financing infrastructure (e.g. PT SMI, ETM, SDG Indonesia One, IIF, Danantara) and periodic reporting and evaluation	Provision of guarantee for electricity transmission and distribution network construction projects in Sulawesi by PT PII			Ministry of Finance	Ministry of National Development Planning/ Bappenas, PT SMI, IIF, Danantara, JETP, PT PII, financial institutions
Limited funding sources for non-commercial electricity projects (e.g. power grid construction and early retirement of power plants)		Electricity grid construction projects are designated as PPP and receive funding	Electricity grid projects in Sulawesi are included in the national PPP list published by Bappenas						
		Framework for industrial decarbonization project strengthened	The development of a blended financing guideline that clarifies the risk-sharing scheme between the public and private sectors, with Bappenas/ PT SMI acting as the anchor or initial seeder of the financing	Preparation of a list of nickel industry decarbonization projects that are eligible for financing through the PPP scheme and included in the national pipeline of Bappenas	• Distribution of funds through a blended financing scheme by BPN and/or PT SMI • Strengthening the reporting system and periodic monitoring of the achievement and use of funds			Ministry of Finance	National Development Bank, PT SMI, Ministry of National Development Planning/ Bappenas
				Preparation of regulations for the establishment of the National Development Bank (BPN) to support the financing of high-risk projects.					

■ Challenge ■ Action Plan ■ Policy on technology and infrastructure ■ Policy on standard and regulation ■ Policy on financing and investment

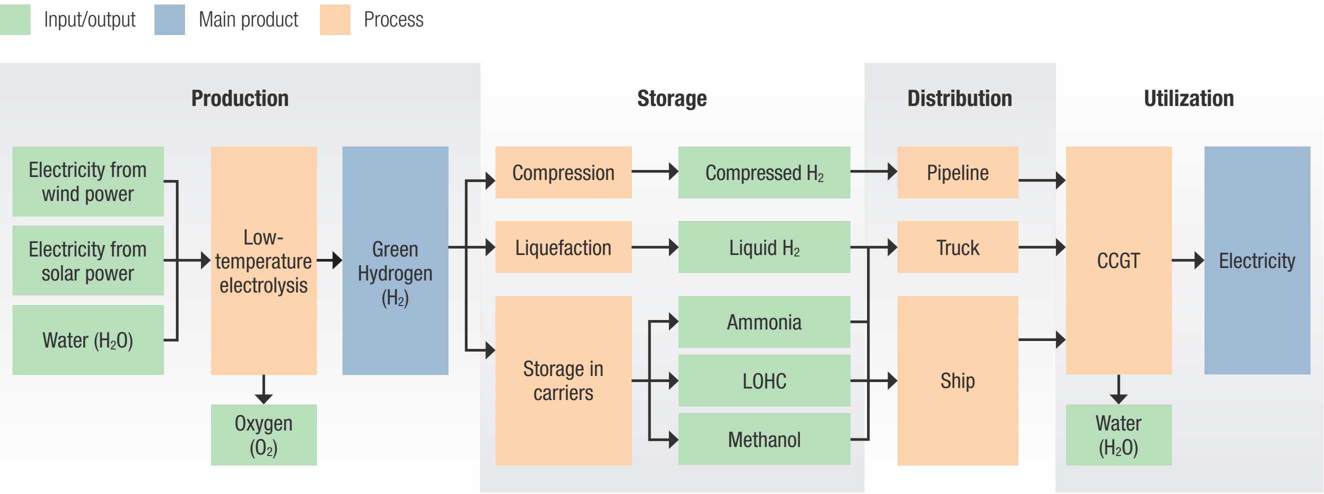
5.2

DEVELOPMENT OF AN INTEGRATED GREEN HYDROGEN SUPPLY CHAIN

To fully decarbonise the power system in Cluster 2—which has limited renewable energy potential—the Ambitious Scenario requires additional clean electricity generated using green hydrogen (power-to-power). A key element in implementing this strategy is ensuring the availability and accessibility of a green hydrogen supply chain for clean power generation in the industrial sector, the affordability of green hydrogen, and the safeguarding of its accountability and sustainability.

Green hydrogen refers to hydrogen produced through water electrolysis, a process that splits water (H_2O) into oxygen (O_2) and hydrogen (H_2). What makes this hydrogen "green" is the use of electricity derived from renewable energy sources such as solar and wind during the electrolysis process. To ensure that the clean electricity produced using green hydrogen is available and accessible, the entire supply chain—from upstream to downstream—must be established, as illustrated in **Figure 76**, to generate the additional clean electricity required for Cluster 2, as referenced in **Figure 70**.

Figure 76.
Green hydrogen supply chain for clean power generation



There are three key infrastructures that must be developed. First is a centralized liquid hydrogen industry. This industry would be responsible for generating or procuring clean electricity, producing green hydrogen, and storing it in a form that is suitable for transportation. The main challenge lies in the demand-supply gap: the projected demand for green hydrogen to decarbonise the nickel industry exceeds the planned national production capacity as outlined in both the Electricity Supply Business Plan (RUKN) and the National Hydrogen and Ammonia Roadmap (RHAN). According to the RUKN 2025–2060, green hydrogen industry development in Papua and East Nusa Tenggara (NTT), scheduled to begin production in 2031, will only be able to generate 0.52 GW of clean electricity by 2045—while the demand is estimated at 5.1 GW, resulting in a deficit of 4.58 GW. Meanwhile, the RHAN projects that by 2045, all green hydrogen produced nationally could generate up to 3.57 GW of clean electricity—still leaving a shortfall of 1.53 GW. Although the deficit under the RHAN is smaller, its projections cannot yet be considered reliable benchmarks due to the lack of clarity regarding production locations and allocation plans for the green hydrogen.

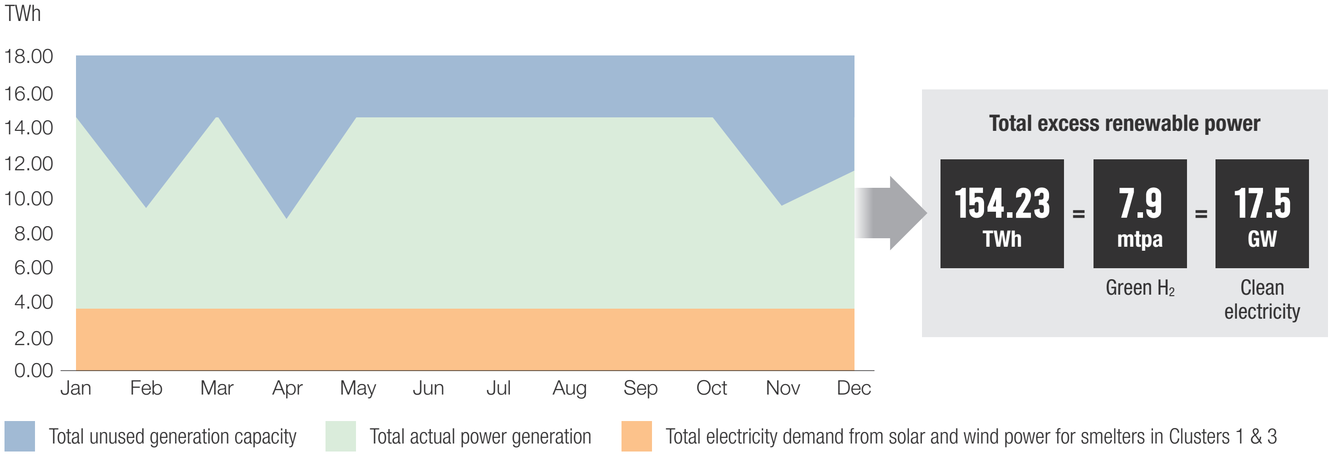
Table 10.
Comparison of nickel industry needs for clean electricity generated from green hydrogen to supply plans in RHAN and RUKN

	Nickel industry needs (GW)	Provision plan in the National Hydrogen and Ammonia Roadmap (PHAN)* (GW)	Provision plan in RUKN for Papua and NTT regions (GW)	Status
2025	0	0	0	The nickel industry did not need hydrogen in this period.
2030	0	0.05 ⬆	0	
2035	0.75	0.52 ⬇	0.092 ⬇	The deficit was 0.23 GW from PHAN and 0.658 GW from RUKN.
2040	4.67	2.045 ⬇	0.229 ⬇	The deficit was 2,625 GW from PHAN and 4,441 GW from RUKN.
2045	5.1	3.57 ⬇	0.527 ⬇	The deficit was 1.53 GW from PHAN and 4.58 GW from RUKN.

**) Processed from the target capacity of the installed electrolyser*

Considering the deficit in the hydrogen supply plan in RUKN and RHAN, we recommend the addition of a centralized liquid hydrogen industry development in Sulawesi that utilizes the remaining renewable energy potential from Clusters 1 and 3. To meet the need for green hydrogen in Cluster 2 which reaches 2.3 mtpa, it is necessary to use unused energy for smelters up to 154.23 TWh/year. To meet this, optimization is carried out to achieve the minimum amount of idle generation capacity. Based on our calculations, a generation capacity is needed with a total annual production of 216.56 TWh. Where, there is an idle generation capacity of up to 20.03 TWh. Therefore, it is necessary to increase the capacity of solar power plants from 16.45 GW to 32.24 GW in Cluster 1, and an additional from 4.39 GW to 60.72 GW in Cluster 3. In addition, it is necessary to increase the capacity of wind power from 0.128 GW to 0.13 GW in Cluster 1 and from 13.15 GW to 88.31 GW in Cluster 3. All of these additional capacity are located within a 20 km range of the planned electricity transmission network within the RUKN. Where, the annual energy generation produced can meet all the clean electricity needs for smelters in Clusters 1 and 3, as well as the production of green hydrogen needed to generate electricity in Cluster 2.

Figure 77.
The amount of excess net electricity produced by Clusters 1 and 3 if the generation is carried out under optimal conditions



Second, hydrogen distribution infrastructure. Green hydrogen must be transported from Sulawesi, East Nusa Tenggara (NTT), and Papua to Cluster 2 in North Maluku. Unlike the production phase of green hydrogen—which has already begun pilot testing in Indonesia—the storage and distribution stages remain significantly underdeveloped. As a result, the RHAN designates the Initiation Phase (2025–2034) for conducting studies on hydrogen storage, preparing infrastructure, and demonstrating hydrogen transportation by land and sea. Under the Ambitious Scenario, green hydrogen is stored in liquid form and transported by ship, requiring research on liquid hydrogen storage tanks, studies on low-carbon marine fuels to ensure that emission reductions from hydrogen use are not offset by shipping emissions, and the development of temporary liquid hydrogen storage infrastructure at ports and logistics hubs.

Third, clean electricity utilization infrastructure. From the port, liquefied hydrogen is brought to the centralized regasification infrastructure located at 2-3 points, some in industrial estate areas considering that the majority of industries in Cluster 2 are located in industrial estates (IWIP and Obi Industrial Park). Hydrogen is then generated at the PLTGU and its net electricity production is channelled to the respective industries. Therefore, investment is needed in regasification plants, power plants, and power terminals per region.

The next element is affordability. The price of green hydrogen and the price of green hydrogen-based electricity sold to the nickel industry are the determining factors for the affordability of this strategy. Based on our modelling, buying green hydrogen at the current average price (2025) to generate clean electricity would result in a negative margin for the industry, reaching -2.45%. Therefore, a special subsidy is needed to reduce the price of green hydrogen that will be used in Cluster 2. To maintain a minimum margin of 10 percent, a cumulative subsidy of USD 50.2 billion is required between 2025 and 2045 to reduce the price of green hydrogen by 97 percent. (from $45,913/TJ to $1,094/TJ). As a result, the net electricity price that needs to be paid by the nickel industry in Cluster 2 is Rp 713.81/kWh, 28% cheaper than the current electricity price.

Figure 78.
Projection of green hydrogen prices with and without subsidy
Thousand USD/TJ

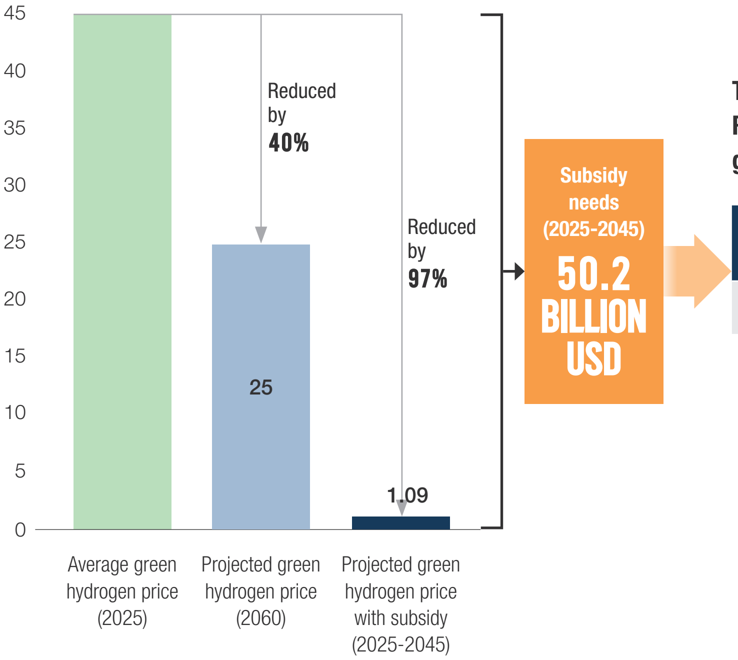


Table 11.
Recommended selling price of electricity from green hydrogen to industry

Cluster	Energy source: BAU (IDR/kWh)	Energy source: Green H_2 (IDR/kWh)
2	996.74	713.81 ⬇

To support this strategy, we see an opportunity through the implementation of Government Regulation (PP) No. 19 of 2025, which will raise the royalty rate for nickel companies producing FeNi and NPI from the current 2% and 5% to 7% of the product price per ton. The increase in state revenue from royalties could be reallocated back to the nickel industry through a targeted subsidy scheme, specifically to support green hydrogen pricing in Cluster 2. To meet the required subsidy levels, it is proposed that 75% of total royalty revenue be reallocated for the purpose of decarbonising the nickel industry.

Given the high dependency of Cluster 2's decarbonization efforts on green hydrogen, financing must also be supported by PPP mechanisms to ensure the development of the necessary supply chain infrastructure—covering production, storage, and transportation. On the hydrogen consumption side, private investment led by the nickel industry (e.g., by industrial park developers) is proposed to finance the construction of PLTGU and supporting infrastructure. This financing strategy can be complemented with fiscal incentives, such as import duty exemptions for key technologies including electrolysers, storage systems, and PLTGU-related technologies across the supply chain.

Finally, a safeguard mechanism is needed to ensure that green hydrogen production adheres to environmental sustainability and emission accountability principles. There are two main challenges in this regard. First, Indonesia currently lacks a national standard defining green hydrogen based on emission intensity. However, such standardization—covering the full supply chain, from electricity sourcing to transport and distribution—is essential to prevent greenwashing and to ensure that emission reduction claims can be verified. At the global level, definitions of low-carbon hydrogen vary. Under mandatory schemes, the EU's Renewable Energy Directive II sets an emission threshold of 3.4 kg CO_2 per kg H_2, while in voluntary frameworks, the China Hydrogen Alliance defines thresholds of 4.9 kg CO_2/kg H_2 for renewable and clean hydrogen, and 14.5 kg CO_2/kg H_2 for low-carbon hydrogen (ESDM, 2025).

Second, there is no formal certification system in place to verify the environmental attributes of clean electricity used in or produced from hydrogen production. Without a system such as Guarantee of Origin (GO) or, in the Indonesian context, Renewable Energy Certificates (RECs), it is difficult to verify that hydrogen is produced from renewable energy and is cleaner than coal-based alternatives. In the European Union, certification schemes for green hydrogen such as CertiHy are already in place. These schemes incorporate requirements on time and location correlation—covering when renewable electricity is produced and whether it is generated at the same site as hydrogen production—as well as additionality and emission intensity. This system can serve as a reference for the development of a green hydrogen certification framework in Indonesia.

Table 12.
Policy framework for developing green hydrogen supply chains for the nickel industry 2025-2045

Policy Direction	**Development of an integrated green hydrogen supply chain**
Objective	**Green hydrogen in Cluster 2 for clean electricity production is supported by an integrated supply chain, cost competitiveness, and strong safeguards.**

Challenge	Action Plan	Measure of Success	Milestone					Lead Agency	Other Related Parties
			2025–2029		2030–2034	2035–2039	2040–2045		
Limited development of hydrogen supply chain infrastructure and policies for the nickel industry	Preparation and implementation of a technical plan for the development of an integrated green hydrogen supply chain in the nickel industry area as a derivative of the national hydrogen strategy document and roadmap and RUKN	Technical plan for the development of an integrated green hydrogen supply chain in the nickel industry area (Sulawesi and Maluku) is implemented	Preparation of a study on the development of green hydrogen supply chains for clean electricity supply in North Maluku (including the determination of models and infrastructure identification for green hydrogen production, storage and distribution methods, clean electricity generation mechanisms, and identification of potential industries/filler actors at each stage of the supply chain)	Determination of KBLI specifically for hydrogen (green)	Pilot project specifically for storage and distribution of green hydrogen, as well as clean electricity generation using PLTGU	0.75 GW of clean electricity is available from 0.34 mtpa of green hydrogen produced using additional clean electricity generation in Sulawesi amounting to: Solar Power Plants: 37.58 GW Solar Power Plants: 36.06 GW	5.1 GW of clean electricity available from 2.3 mtpa of green hydrogen produced using additional clean electricity generation in Sulawesi amounting to: Solar Power Plants: 75,162 GW Solar Power Plants: 72.12 GW	Ministry of Energy and Mineral Resources	PLN, Logistics industry, IPP, nickel industry
			Preparation of demand assessment of the nickel industry	Exploration and negotiation of initial off-take agreements with the nickel industry	Signing of medium-long term off-take agreements	Implementation of regular evaluation and demand mapping to increase the scale of operations and expand the buyer base			
	Preparation of funding schemes and fiscal incentives to support the development and investment of the green hydrogen supply chain	Funding schemes and fiscal incentives for the development of green hydrogen supply chains for clean electricity production are available	Hydrogen industrial construction projects in Sulawesi as well as the construction of green hydrogen-based coal-fired power plants and captive electricity distribution networks in North Maluku are included in the national PPP list issued by Bappenas	Distribution of funds by existing financing infrastructure (e.g. PT SMI, ETM, SDG Indonesia One, IIF, Danantara) and periodic reporting and evaluation	Import duty exemption for import of key equipment such as electrolysers, storage, and more			Ministry of Finance, Ministry of Energy and Mineral Resources	Ministry of National Development Planning/ Bappenas, PT SMI, IIF, Danantara, financial institutions, PT PII
			Provision of guarantees for hydrogen industry construction projects in Sulawesi as well as the construction of green hydrogen-based PLTGU and captive electricity distribution networks in North Maluku by PT PII						PLN, logistics industry, IPP, nickel industry

Challenge	Action Plan	Measure of Success	Milestone					Lead Agency	Other Related Parties
			2025–2029		2030–2034	2035–2039	2040–2045		
Implementing green hydrogen at the prevailing price will result in a margin of -2.45% for the nickel industry	Provision of targeted subsidies for green hydrogen prices for the nickel industry in the North Maluku cluster	Market price of green hydrogen and clean electricity from customized green hydrogen	Preparation of a study on need justification, price simulation, and mechanism of reallocation of state revenues (from royalties paid by the nickel industry) to facilitate green hydrogen subsidies for the nickel industry in North Maluku in order to maintain a balance between the achievement of emission reduction targets and industrial economic stability	The issuance of regulations or ministerial decrees on green hydrogen subsidies for the nickel industry in North Maluku	The selling price of green hydrogen from PLN to IPPs/ industries follows the recommended price after the implementation of the subsidy to maintain the min. 10% margin for nickel industry in North Maluku			Ministry of Finance, Ministry of Energy and Mineral Resources	PLN, IPP, nickel industry
					The selling price of off-grid net electricity from IPPs to industry follows the recommended price, the impact of subsidies on the price of green hydrogen, to maintain the min. 10% margin for nickel industry in North Maluku				
There is no definition of green hydrogen and how to verify the environmental attributes of green hydrogen	Setting technical and environmental standards for green hydrogen (and the clean electricity produced, if required)	National standards for green hydrogen available	Preparation of SNI for green hydrogen used for clean electricity production		Development and testing of green hydrogen certification mechanisms	Implementation of certification in industry and periodic evaluations		Ministry of Energy and Mineral Resources, Ministry of Industry	BSN, LSPro, a third-party registry system provider
		The threshold for green hydrogen and/or electricity emission intensity from green hydrogen and its certification mechanism are available in Indonesia	Preparation of definitions and thresholds for the intensity of green hydrogen and/or electricity emissions from green hydrogen in government regulations that refer to international practices						

🟦 Challenge ◼ Action Plan 🟩 Policy on technology and infrastructure 🟦 Policy on standard and regulation 🟧 Policy on financing and investment

5.3

DEVELOPMENT OF SUSTAINABLE BIOMASS SUPPLY CHAIN FOR BIOREDUCTANT PRODUCTION

Another major source of emissions in the nickel industry is the calcine reduction process, which accounts for approximately 26% of the industry's total emissions. In this process, nickel (Ni) and iron (Fe) metals are reduced from dried nickel ore using anthracite coal as a reductant. To decarbonise this activity, coal will be substituted with bioreductants. Therefore, key elements in the implementation of this strategy are the availability and affordability of the biomass supply chain in meeting production quantities for decarbonization (availability and accessibility), strict technical and environmental quality standards (safeguard), and price strategies that support a sustainable biomass business model (affordability).

Regarding the availability and accessibility aspects, the implementation of the Ambitious Scenario for decarbonization of the nickel industry requires 9.6 million tons of biomass per year[6] at the highest adoption conditions as shown in **Figure 70**. However, there are three challenges, namely insufficient biomass production, instability of quantity and quality of supply, and the absence of pre-treatment facilities. First, the amount of national biomass production is not enough to meet the needs of decarbonization. Palm shell charcoal is the type of biomass that is most in demand by smelters because its characteristics are similar to coal and have been used to a limited extent. However, the national production potential is only around 6.56 million tons/year (only 68.3% of the need) and is concentrated in Sumatra and Kalimantan. Sulawesi can only contribute 58.7 thousand tons/year (about 6.1% of the need). At the same time, palm oil shells cannot be assumed to be entirely available to the nickel industry. In practice, palm shell waste is widely reused internally by the agricultural industry or nearby industries such as pulp and paper for co-firing captive coal-fired power plants in mills.

Second, the more diverse the type of biomass used, the more varied the location and harvesting cycle (as shown by **Figure 78**). This can disrupt supply stability and reduce the industry's confidence to transition. And third, not all biomass has immediately met the quality requirements to be used directly as a reductant. Before it can be used in a rotary kiln, biomass must first be treated to reduce the content of moisture, ash, and volatile matter. To achieve this, it is necessary to carry out pre-treatment to process raw biomass into biochar through the pyrolysis process.

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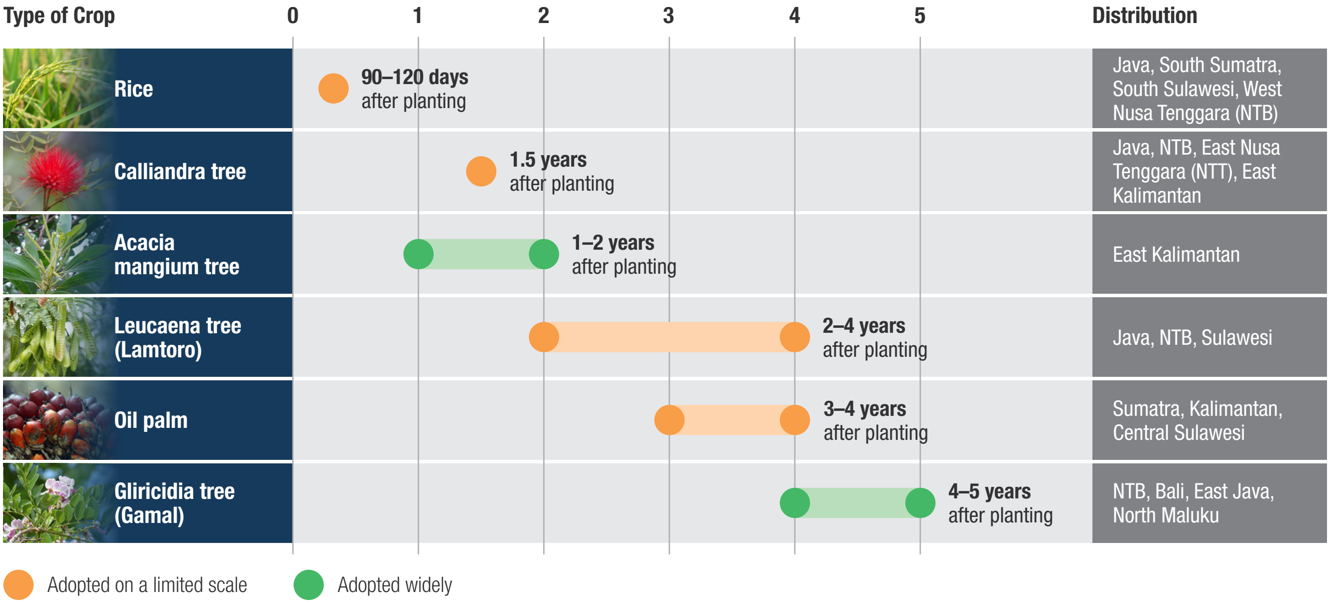
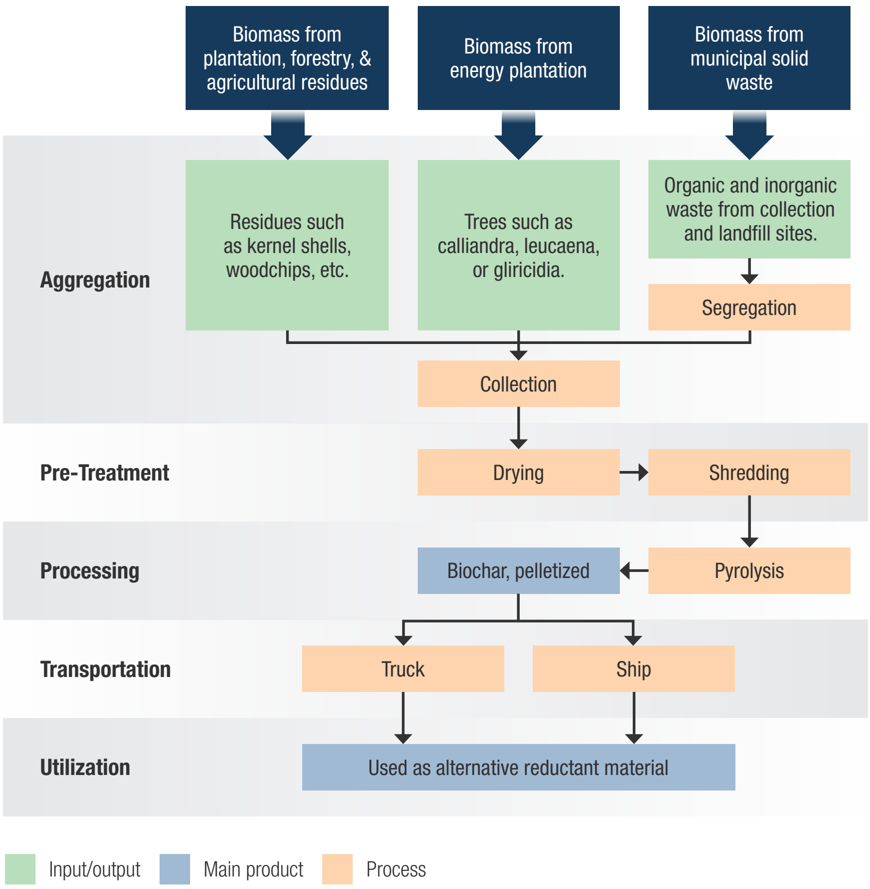
[6] Equivalent of palm oil shell

Figure 79.
Variations in location and harvest time of some biomass sources



To meet national biomass demand, planning cannot be conducted on a commodity-by-commodity basis—it must be approached in an integrated manner. Therefore, an integrated supply chain is needed, led by a new industrial player: the biochar production industry. This industry will play a central role as a national-level demand planner, connecting upstream biomass producers, the nickel industry, and transportation service providers. It will also be responsible for identifying strategies and new plant-based commodities to fill national supply gaps, innovating in technical diversification, blending, and planting cycle engineering to ensure reliable biomass feedstock availability. Furthermore, this industry will carry out necessary pre-treatment, technology research, and market development efforts.

Figure 80.
Biomass-based reductant supply chain



In the initial iteration, there are three potential sources of biomass, namely 1) plantation, forestry, and agricultural waste; 2) Energy Plantation Forests (HTE); and 3) municipal solid waste (MSW). The utilization of production sources 1 and 2 is common in Indonesia – although HTE is more often used for the procurement of co-firing raw materials for coal-fired power plants, while the utilization of production sources 3 still requires research and piloting. The government has also allocated 15,000 ha for HTE in the 2020-2024 KLHK Strategic Plan and launched HTE business licenses of up to 1 million ha, but the implementation is still minimal.

In the operation of the supply chain, the biomass raw material producers, biochar manufacturers, and transportation service providers will each play distinct roles. Industries that provide raw materials (such as the plantation, forestry, agriculture, and waste management industries) play a role in land clearing, planting, and harvesting crops or waste collection and sorting. Intervention in the industry can be carried out through the implementation of regulations related to recycling rates so that the existence of waste supply for the industry after that is guaranteed. This is in line with the government's plan to issue a Presidential Regulation that will require and combine the handling of household waste and marine debris at the regional level, thereby providing certainty of the availability of biomass raw material sources from MSW by local governments. Furthermore, the biochar producing industry plays a role in collecting biomass, carrying out pre-treatment, and pyrolysis until biochar is produced. Specifically for the HTE scheme, this industry can also act as a provider of raw materials by applying for an industrial crop business license. Finally, the transportation service plays a role in mobilizing biochar to the nickel industry. The central position in this scheme has actually begun to be carried out on a limited basis by PLN Energi Primer Indonesia (EPI), although it is still focused on providing biomass for electricity generation.

Drawing from best practices in mainstreaming biofuels and biogas, the realization of such a biomass supply chain requires the following: 1) A national strategy or regulation that sets production targets for bio-reductants, to provide legal standing and formal urgency for supply chain development; 2) An action plan for supply chain development and the establishment of a specific Industrial Classification Code (KBLI) for bio-reductant producers, to regulate the industry's operations and mandates; and 3) A national product standard (SNI) for bio-reductant quality, differentiated by biomass type. To date, none of these three elements are yet in place in Indonesia.

From a safeguard perspective, bio-reductant production presents technical and environmental concerns. Technical concerns—particularly quality consistency—can be addressed through the issuance of SNI. On the environmental side, there are concerns about deforestation risks, especially if biomass is sourced from commercial timber plantations (HTE). Thus, the use of bio-reductants carries the potential for indirect emissions arising from the production process itself, including land clearing, feedstock collection, machinery use for drying and shredding, and fuel consumption in transportation.

With regard to emissions, as with green hydrogen, Indonesia currently lacks formal regulations or standards defining sustainable biomass or bio-reductant criteria. However, voluntary standards such as RSPO and ISPO (for palm oil), or FSC (for wood chips and wood pellets), can serve as initial references. These frameworks typically include provisions such as prohibitions on deforestation, requirements for sustainable forest management practices, and transparency in life cycle assessment (LCA) calculations.

Concerning deforestation, according to the IEA, key principles for sustainable biomass production include 1) prioritizing the use of waste and plant residues, not clearing new forests; and 2) if planting is needed, it must be on degraded land. Production Routes 1 and 3 in Indonesia are already aligned with the first principle. As for the second, the government has pledged that energy plantations (HTE) will be developed on rehabilitated land rather than natural forests (FWI, 2025). Policy-wise, Minister of Environment Regulation No. 62 of 2019 mandates that HTE should be located on nonproductive forest land. However, field practices often deviate from policy: natural forests continue to be cleared for energy crops such as sengon, gamal, and kaliandra (Tempo, 2025). Therefore, any HTE expansion must be accompanied by robust law enforcement to ensure compliance with sustainability commitments.

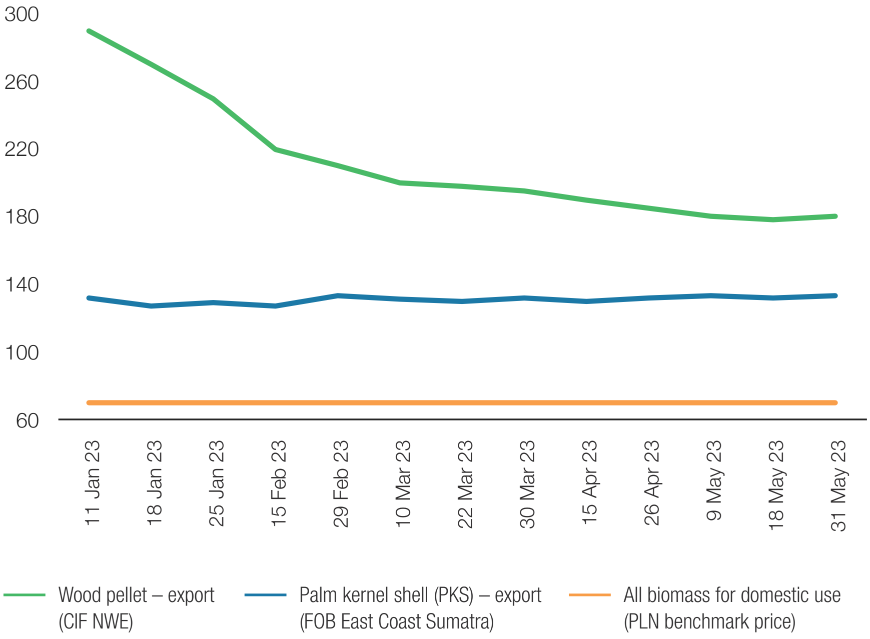
Finally, from the affordability aspect, the procurement of bioreductants for industry is targeted as a solution that depends entirely on market mechanisms, therefore the above business models in the supply chain must run. Currently, in the midst of limited biomass production capacity in Indonesia, many industries have chosen to export wood pellet biomass to South Korea and Japan, due to the high selling price of biomass to the global market, which reaches $127-133/ton (2023 price). This price is significantly higher than the domestic biomass selling price, which is currently dominated by sales to PLN for power generation and competes with the coal DMO price of $70 per ton. According to data from BPS, the export volume of palm oil shells in 2022 can reach 4.65 million tons, around 23% of the decarbonization needs of the nickel industry.

Therefore, this roadmap recommends setting a biomass reference price of $140/ton, which is also in line with MEBI (2023) recommendations. Our model has simulated that the industry's margin will remain at least above 10% for each cluster, so that this price can motivate the biomass supplier industry to sell more to the domestic market while not reducing the purchasing power of the nickel industry. In addition, to avoid fluctuations in commodity prices, the government needs to set a reference price for biomass (HBmA) that is in line with the recommended price which currently does not exist. Other energy sources already have reference prices, such as natural gas and biodiesel.

In addition, in financing the development of biomass supply chains for bioreductant production, the proposed scheme is through private investment. One example is the utilization of commercial loans for the development of business lines and production scale in the private sector, such as PT PLN EPI which currently supplies biomass on a limited basis for PLN's power plants. At the same time, palm oil export levy funds, which are currently widely used for biodiesel development, also have the potential to be used for the development of bioreductant production supply chains in Indonesia. It is necessary to conduct a separate study to review the feasibility and appropriate amount of allocation.

Figure 81.
Biomass sales price for domestic and export market, 2023[7]

USD/ton



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[7] Argus (2023), PLN (2023)

Table 13.
Policy framework to develop a sustainable biomass chain for bioreductant production for the nickel industry 2025-2045

Policy direction	**Development of sustainable biomass supply chain**
Objective	**Bioreductants are supplied through a reliable supply chain, comply with strict quality and technical standards, and are priced to support a sustainable domestic business model.**

Challenge	Action Plan	Measure of Success	Milestone					Lead Agency	Other Related Parties
			2025–2029		2030–2034	2035–2039	2040–2045		
The current levels of national biomass generation and biochar production fall well short of the amounts required to decarbonize the nickel industry.	Establishment of the basic infrastructure of the sustainable biomass supply chain	National strategies or regulations that regulate biomass production targets for reductant production needs are available	Ratification of the government's strategic document on biomass production targets for the needs of national reductant production	Determination of KBLI for bioreductants	1.9 million tonnes of biomass available - Cluster 1 (Central Sulawesi): 0.4 million tons - Cluster 2 (North Maluku): 1.2 million tons - Cluster 3 (South and Southeast Sulawesi): 0.3 million tonnes	5.3 million tonnes of biomass available - Cluster 1 (Central Sulawesi): 1.2 million tons - Cluster 2 (North Maluku): 3.1 million tonnes - Cluster 3 (South and Southeast Sulawesi): 1 million tonnes	9.6 million tonnes of biomass available - Cluster 1 (Central Sulawesi): 3.1 million tons - Cluster 2 (North Maluku): 3.9 million tons - Cluster 3 (South and Southeast Sulawesi): 2.6 million tonnes	Ministry of Energy and Mineral Resources	PLN EPI, Biomass producer industry, logistics industry, local government, nickel industry
			Ratification of regulations that set recycling rates for biomass-producing industries/actors to ensure the availability of biomass raw material sources						
Greater diversity in the types of biomass used will result in wider variation in sourcing locations and harvest cycles.		Action plan for the development of the biomass supply chain for the needs of reducing the production of reductants is carried out	Preparation of a master plan for sustainable biomass supply chain development (including mapping raw material potential, prioritization of raw materials, demand fulfilment strategies, and potential industries/ actors to fill each stage of the supply chain)	Pilot project production and partnership scheme of bioreductants					
			Preparation of demand assessment of the nickel industry	Exploration and negotiation of initial off-take agreements with the nickel industry	Signing of medium-long term off-take agreements	Implementation of regular evaluation and demand mapping to increase the scale of operations and expand the buyer base			
	Preparation of funding schemes and fiscal incentives to support supply chain development	Funding schemes and fiscal incentives for the development of biomass supply chains for the needs of reducing reductants are available	Preparation of a study to allocate as a source of palm oil from the export levy (levy) for the development of the biomass supply chain for the needs of reducing reductants	Implementation of study results to reduce CAPEX and subsidize engineering research for biochar-producing industries	Provision of guarantees for industrial construction projects of bioreductant producers by PT PII			Ministry of Finance, Ministry of Energy and Mineral Resources	PLN EPI, The Plantation Fund Management Agency (BPDP), PT PII, financial institutions

Challenge	Action Plan	Measure of Success	Milestone					Lead Agency	Other Related Parties
			2025–2029		2030–2034	2035–2039	2040–2045		
Domestic biomass shortages persist as producers prioritize more profitable export markets.	Determination of sustainable biomass and/ or bioreductant reference prices	The business model of sustainable biomass supply chain in the country is running well	The determination of the Reference Biomass Price (HBmA) through the Ministry of Energy and Mineral Resources is higher than the average export price but still maintains a min. margin of 10% for industries throughout the cluster		The price of bioreductants follows HBmA			Ministry of Finance, Ministry of Energy and Mineral Resources	PLN EPI
Bioreductant is a new product and is still in the development stage, so it is feared that it will produce inconsistencies in terms of technical quality	Determination of technical and environmental standards for biomass and/or bioreductants	National standards for bioreductants are available	Issuance of national standards on sustainable biomass that are in line with international standards (including emission intensity, traceability, obligation to implement sustainable land management practices)	SNI issuance for sustainable bioreductants differentiated by biomass type	Implementation of periodic certification and evaluation			Ministry of Energy and Mineral Resources, Ministry of Industry	BSN, LSPro
Bioreductant production risks increasing deforestation (specifically HTE) and emissions, especially from land clearing		Law enforcement and monitoring system for HTE management run more tightly	The implementation of the evaluation of the running of HTE so far has mainly been in the aspect of land selection that must remain in degraded areas, not natural forests	Issuance of derivative regulations on HTE supervision guidelines	Implementation of periodic supervision, reporting, and evaluation			Ministry of Environment, Ministry of Forestry	Local government

■ Challenge ■ Action Plan ■ Policy on technology and infrastructure ■ Policy on standard and regulation ■ Policy on financing and investment

5.4

EXPANSION OF NATURAL GAS SUPPLY FOR METALLURGICAL COAL SUBSTITUTION

To reduce emissions from rotary dryers and rotary kilns, it is necessary to replace coal fuel with LNG. To be able to replace coal by ensuring that each smelter can produce products according to its capacity, there are three criteria that must be met, namely the availability of LNG in accordance with the capacity needed for decarbonization (availability), access to reliable LNG (accessibility), and ensuring LNG prices until they reach the smelter (affordability).

Regarding the availability aspect, Cluster 1 requires LNG consumption of up to 1 mtpa. Meanwhile, in Cluster 3, there is a need for LNG consumption of up to 0.8 mtpa. Based on Indonesia's Gas Balance 2018-2027, it is known that there is a total existing gas supply in Sulawesi that reaches 2.9 mtpa, namely from JOBP-ME&PTS-Senoro and Matindok. LNG needs from smelters in Clusters 1 and 3 can be fully met from the two gas fields in Central Sulawesi. In addition, in 2024, PT Pertamina EP has managed to find new gas reserves in the Tedong Well with a potential capacity of 11,871 MMSCFD, which is equivalent to 82.8 mtpa located in North Morowali, Central Sulawesi. The construction of gas fields at the location of this new well can meet the overall LNG needs for smelters in Clusters 1 and 3 without disrupting the existing LNG supply balance.

Meanwhile, in Cluster 2, with a need of up to 4.1 mtpa, it is known that there are no existing LNG terminals in operation. However, based on Indonesia's Gas Balance 2018-2027, it is known that there is an LNG production capacity from the Masela Gas Field located in Maluku up to 3.02 mtpa. By 2025, it is known that INPEX Masela, Ltd., a subsidiary of INPEX Corporation has officially started the initiation phase of Front-End Engineering Design (FEED) for the construction of an onshore LNG refinery. It is planned that the Abadi onshore LNG refinery project in Masela will consist of two refinery units with a total production capacity of 9.5 mtpa. So, with the optimization of the construction of the Masela LNG refinery, the LNG needs in Cluster 2 can be met. To ensure the achievement of the construction of new natural gas fields such as the Tedong Well and the Abadi Gas Field in Masela, the government is expected to provide a legal basis for the implementation of development projects by revising the national natural gas balance and designating it as a National Strategic Project.

Regarding accessibility, referring to the National Natural Gas Transmission and Distribution Network Master Plan for 2024-2033 through the Ministry of Energy and Mineral Resources Number: 173.K/MG.01/MEM/M/2024, it is known that there are no plans to build LNG transmission and distribution networks in Sulawesi and Maluku. Thus, the distribution of natural gas through gas pipelines is not possible with the plan until 2033. In addition to transporting natural gas in the gas phase, LNG transportation by sea is also considered promising. The location of the nickel smelter, which is entirely near the sea with port facilities that have been integrated with the smelter area, can be used as a satellite terminal without the need for a secondary terminal centrally. However, the use of satellite terminals in each port owned by each smelter requires additional investment in the form of storage tanks, regasification facilities, and gas pipelines at each smelter port. The capacity of LNG storage tanks in each smelter will depend on the LNG needs and the capacity of the LNG Carrier Vessels to be used.

The capacity of storage tanks and tankers will determine the number of ship rides that will affect the total cost of purchasing LNG at the plant gate and the need for LNG satellite storage capacity. Collaborating with adjacent smelter companies can also reduce costs, by using larger capacity tankers, to reduce the amount of idle LNG tanker capacity. For a small number of smelters located far from the sea, land transportation modes using ISO tankers or using gas pipelines connected from the satellite terminals of the nearest smelter company can be considered. Smelter companies that fall into this category can work with the nearest smelter company that has a port to provide storage tanks and/or regasification facilities.

An in-depth study by the relevant ministries and each smelter is needed to determine the scenario of providing LNG with the lowest cost.

Figure 82.
LNG preparation scenario for nickel industry

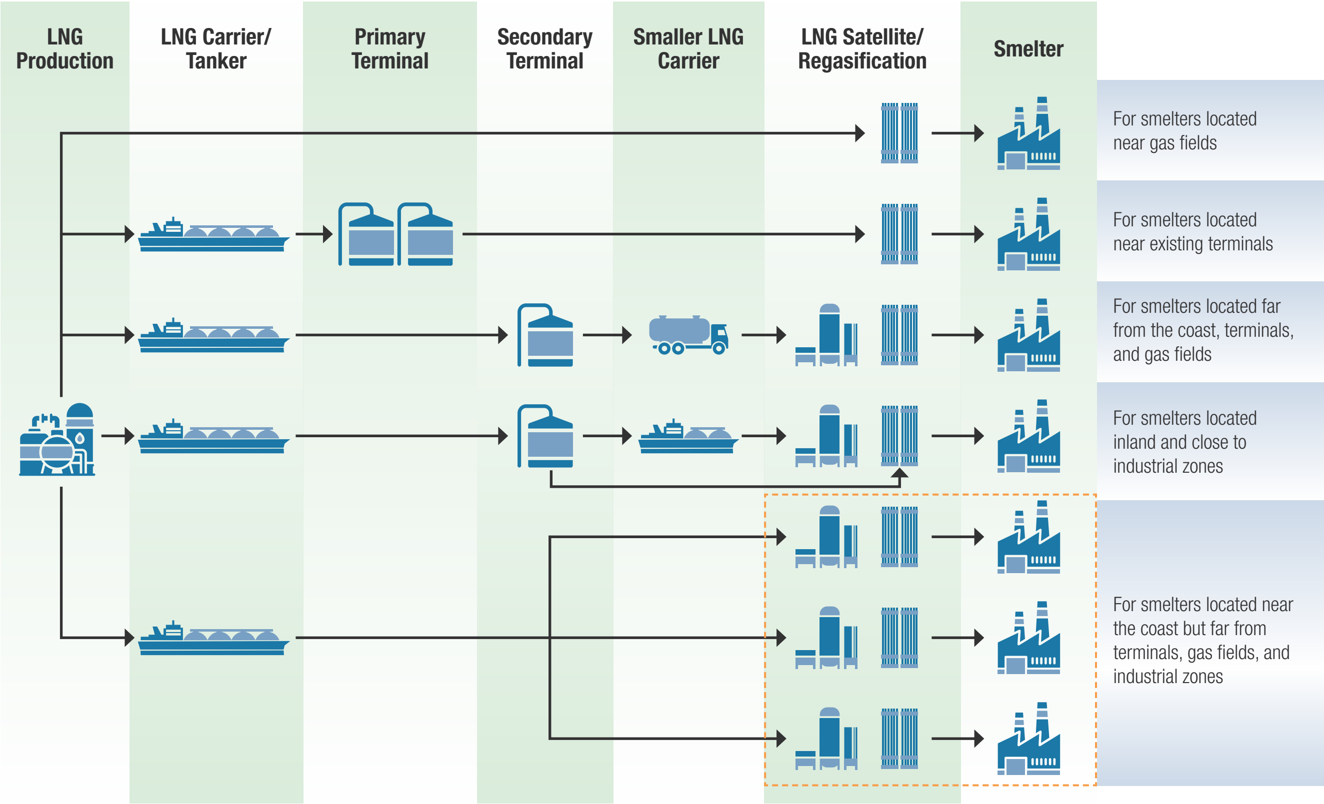


Table 14.
List of LNG producers

Facility Name	Capacity (mtpa)	Location
JOBP-ME&PTS-Senoro	2.183	Banggai Regency, Central Sulawesi
Stuttgart	0.725	Banggai Regency, Central Sulawesi
Tedong Well (potential)	82.763	North Morowali Regency, Central Sulawesi
Muscle	9.5	Masela Island, Southwest Maluku

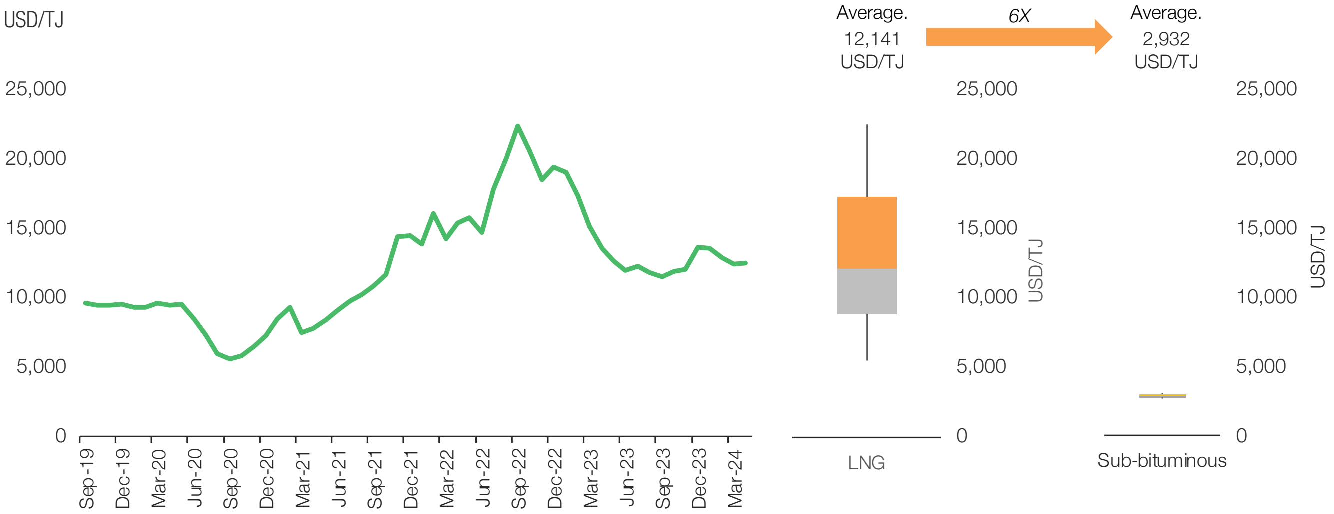
Table 15.
List of primary terminals and LNG regasification facilities

Facility Name	Capacity (mtpa)	Location
Donggi-Senoro LNG Terminal	2	Luwuk, Central Sulawesi
Palu LNG Terminal	2	Palu, Central Sulawesi
Sengkang LNG Terminal	0.5	South Sulawesi coastline
Gorontalo FSRU	0.2	Gorontalo
Amurang FSRU	0.1	Amurang, North Sulawesi

Following a study to identify the most cost-effective natural gas distribution scenario, each responsible entity must prepare plans and carry out the construction of additional infrastructure. Primary terminals and regasification facilities in primary terminals and gas pipelines are expected to be the full responsibility of the government. Secondary terminal facilities can be the responsibility of the government or industrial estates. Meanwhile, satellite storage and regasification facilities are the responsibility of each smelter and industrial estate. The infrastructure planning is expected to have a legal basis for implementation through the revision of the Decree of the Minister of Energy and Mineral Resources No. 173 of 2024.

Regarding affordability, LNG prices in Indonesia fluctuate depending on domestic and global supply and demand conditions. Based on LNG price data from September 2019 to March 2024, LNG prices fluctuate with a minimum price of 5,573 USD/TJ and a maximum of 22,492 USD/TJ. The average 5-yearly LNG price is estimated to reach 12,141 USD/TJ, which is almost 6 times higher than coal.

Figure 83.
Comparison of LNG prices with coal prices



Through Ministerial Decree No. 76 of 2025, the Government of Indonesia has regulated special natural gas pricing (HGBT) for seven industrial sectors. This regulation sets a ceiling price for LNG at the plant gate ranging from USD 5,687 per TJ (equivalent to USD 6 per MMBtu) to USD 6,635 per TJ (equivalent to USD 7 per MMBtu). However, the nickel industry is not included as a recipient of the capped LNG price under this regulation.

According to modelling results, in order to secure a total margin of over 10% for each industrial cluster, it is necessary to establish a special natural gas price (HGBT) for the nickel industry—particularly for pyrometallurgical production routes. The gas price should be capped at a maximum of USD 6,161 per TJ (equivalent to USD 6.5 per MMBtu). This pricing policy could be supported through allocation from new LNG fields, specifically Tedong Well and the Masela LNG Field, by utilizing a mechanism that reduces non-tax state revenue (PNBP) from the oil and gas sector. Implementing the HGBT policy for these new gas sources—dedicated to supplying nickel smelters—would also help de-risk gas development projects by providing more demand certainty. Moreover, considering that some industries designated as HGBT recipients have yet to receive LNG supply in practice, any expansion of the beneficiary sectors must be accompanied by improved governance in LNG distribution, including regular monitoring and audits of energy recipients.

Lastly, the proposed financing scheme for the construction of LNG production and distribution infrastructure is through blended financing, aimed at encouraging private sector participation in Indonesia's LNG sector (e.g., Medco, Inpex, Shell, Pertamina). To enhance investment feasibility and mitigate early-stage risks, guarantees from non-bank financial institutions such as PT Penjaminan Infrastruktur Indonesia (PII) or multilateral agencies are also recommended. This scheme is considered appropriate, given the high profitability potential of the project and its strategic role in supporting the national energy transition. Meanwhile, the construction of regasification plant facilities is recommended to adopt a shared regasification facilities model or an industrial cluster approach within each nickel industrial zone. This approach is expected to improve both cost and operational efficiency. The development of such facilities would be funded through individual investments by each nickel industry player, for example via commercial loans.

Table 16.
Policy framework to expand the supply of natural gas for metallurgical coal substitution in the nickel industry 2025-2045

Policy Direction	**Expansion of Natural Gas Supply for Metallurgical Coal Substitution in the Nickel Industry**
Objective	**Sufficient, accessible, and cost-competitive natural gas supply to replace metallurgical coal**

Challenge	Action Plan	Measure of Success	Milestone					Lead Agency	Other Related Parties
			2025–2029		2030–2034	2035–2039	2040–2045		
Existing natural gas production capacity in Sulawesi and North Maluku has not been designated to support de-carbonization in the nickel industry	Updating of national natural gas planning documents and regulations	Target of field construction and natural gas supply infrastructure with capacity that meets the needs of renewable and implemented nickel smelters	Revision of Indonesia's gas balance document that takes into account the gas potential from new wells in North Morowali (Tedong Well) and natural gas needs for nickel smelters in Sulawesi and North Maluku	Preparation of a field construction master plan and natural gas supply infrastructure to meet the decarbonization needs of the nickel industry (including location determination, natural gas supply scenarios, and identification of required infrastructure)	1.84 mtpa LNG available - Clusters 1 and 3 (Sulawesi): 0.42 mtpa - Cluster 2 (North Maluku): 1.4 mtpa	4.68 mtpa LNG available - Clusters 1 and 3 (Sulawesi): 1.18 mtpa - Cluster 2 (North Maluku): 3.5 mtpa	5.82 mtpa LNG available - Clusters 1 and 3 (Sulawesi): 1.72 mtpa - Cluster 2 (North Maluku): 4.1 mtpa	Ministry of Energy and Mineral Resources	Pertamina, Inpex Masela, Ltd., Medco E&P, nickel industry
			Setting gas production targets and construction of gas wells with capacity in accordance with the decarbonization needs of nickel smelters every year on the National Natural Gas Roadmap						
Limited natural gas supply infrastructure and facilities to nickel producers (1/2)			Revision of the Decree of the Minister of Energy and Mineral Resources No. 173 of 2024 with the determination of the target for the development of natural gas supply infrastructure from gas fields allocated for the decarbonization of the nickel industry to nickel smelters	Determination of the Tedong Gas Field and the Masela Gas Field as National Strategic Projects with the main allocation for the purpose of decarbonising nickel smelters in Sulawesi and North Maluku					
			Preparation of feasibility study and engineering design for the implementation of the master plan		Regulatory reform to accelerate the addendum of special terminal permits (tersus)				

Challenge	Action Plan	Measure of Success	Milestone					Lead Agency	Other Related Parties
			2025–2029		2030–2034	2035–2039	2040–2045		
Limited natural gas supply infrastructure and facilities to nickel producers (2/2)	Provision of fiscal assistance to support the development and investment of natural gas infrastructure	Funding and fiscal and operational incentives and schemes Development of natural gas supply infrastructure for coal substitution available	Preparation of demand assessment of the nickel industry	Signing of an off-take agreement between the Smelter in Sulawesi with the Donggi Matindok Gas Field, the Eastern Indonesia Regional Field in North Morowali and the Smelter in North Maluku with the Abadi Gas Field in Masela	Implementation of regular evaluation and demand mapping to increase the scale of operations and expand the buyer base			Ministry of Finance, Ministry of Energy and Mineral Resources	Pertamina, Inpex Masela, Ltd., Medco E&P, nickel industry, non-bank financial institution
			Import duty exemption for import of key technology (e.g. regasification plant)		Provision of guarantees for field construction projects and natural gas distribution infrastructure by non-bank financial institutions				
Volatile natural gas prices, with the average historical price being nearly 6 times higher than coal	Determination of certain natural gas (HGBT) prices for nickel producers, especially those through pyrometallurgical production lines	Specific natural gas (HGBT) prices for the nickel industry are set	Preparation of a study on the justification of needs and mechanism for reallocation of state revenues to facilitate HGBT for the nickel industry to maintain a balance between the achievement of emission reduction targets and industrial economic stability	Revision of the Decree of the Minister of Energy and Mineral Resources No. 76 of 2025 to facilitate the expansion of HGBT for the nickel industry	Implementation of HGBT for the nickel industry			Ministry of Energy and Mineral Resources, Ministry of Industry, Ministry of Finance	Pertamina, Inpex Masela, Ltd., Medco E&P
Not all industries that have received HGBT allocation get the supply of natural gas as needed		The governance of natural gas distribution with HGBT runs well and ensures the distribution of supply in accordance with the amount in the off-take agreement			Periodic monitoring and evaluation of the accuracy of HGBT allocated natural gas distribution to the nickel industry				

🟦 Challenge ⬛ Action Plan 🟩 Policy on technology and infrastructure 🟦 Policy on standard and regulation 🟧 Policy on financing and investment

5.5

EXPANSION OF ENERGY EFFICIENCY ADOPTION

Under existing conditions, technologies for waste heat recovery from rotary kilns, electric furnaces, and slag are already commercially available. The main challenge in implementing this technology lies in the plant layout design, particularly in the distance between heat-generating units (rotary kiln, electric furnace, and slag granulator) and the heat receiver unit, namely the rotary dryer. The greater the distance between these units, the more heat is lost through piping, and the less residual heat can be recovered.

In Indonesia, many RKEF smelters were built with spatially dispersed layouts, making it difficult to implement optimal waste heat recovery systems. These smelters are generally older facilities. In contrast, smelters constructed in recent years are typically designed in a more compact layout, with shorter distances between processing units, enabling improved energy efficiency optimization. In light of this, this roadmap targets the implementation of decarbonization actions in 80% of existing operating smelters. Meanwhile, all RKEF smelters commencing operations after the initial adoption year (2030) will be required to adopt waste heat recovery technologies. Based on Best Available Technology (BAT), the potential for waste heat recovery in rotary dryer units is estimated at 34% of exhaust heat from electric furnaces, 14% from rotary kilns, and 20% from slag granulators.

The Government of Indonesia, through Government Regulation No. 33 of 2023 and Minister of Energy and Mineral Resources Regulation No. 8 of 2025, has mandated the implementation of energy conservation through energy management for industries consuming energy equal to or greater than 4,000 tons of oil equivalent (TOE) per year, which is equivalent to 0.042 terajoules (TJ) per year. Based on these criteria, all nickel smelters operating through the pyrometallurgical production route should fall under the category of industries required to implement energy conservation through energy management.

Strict enforcement of these regulations, particularly for smelter companies operating via the RKEF production process, is deemed essential to ensure the achievement of energy efficiency targets. The government may develop specific energy efficiency targets for RKEF-based smelter companies as a derivative of the existing ministerial regulation. Collaboration with the Ministry of Industry and the Ministry of Environment is expected to ensure that the assessment, management, and periodic monitoring of energy consumption are incorporated into Environmental Impact Assessments (EIA) and detailed Environmental Management and Monitoring Plans (RKL-RPL). Minimum efficiency targets can serve as a standard for environmental feasibility and compliance levels within regulatory reporting.

The government is also encouraged to facilitate technology transfer from existing research institutions and technology inventors/providers, and to compile a database of successful case studies in energy efficiency within the nickel industry. This will enable the development of a technology and innovation catalogue for energy efficiency in nickel smelters, along with an updated energy efficiency guideline, to be revised periodically.
The Ministry of Energy and Mineral Resources already has an Energy Conservation Information System (SINERGI) as an integrated platform in energy reporting efforts. The government's information system offers a range of features to support businesses in carrying out energy conservation measures. Through this information system, the government can integrate energy conservation reporting and planning guidelines accompanied by specific energy efficiency targets for nickel smelters.

In parallel, the government needs to promote technology transfer for energy efficiency through more concrete collaboration between research institutions such as BRIN, universities, technology providers, and industry players. One actionable step is to develop existing metallurgical research centres into application-oriented hubs and position them as pilot project centres for technology commercialization. Drawing lessons from China's technology transfer policy, the government may consider establishing dedicated technology research institutions and fostering strong partnerships with industry stakeholders. It is also necessary to increase the budget for thematic research purposes related to the nickel industry, one of which is related to energy efficiency, to increase the competitiveness of the Indonesian nickel industry.

To support financing for the integration of energy efficiency technologies, the OJK is expected to include specific criteria in its green taxonomy, particularly for energy efficiency activities involving waste heat recovery. The inclusion of such criteria would allow waste heat recovery projects to be recognized as green activities, qualifying them for funding from commercial banks and development banks. OJK may refer to international best practices, such as the European Union's Taxonomy for Sustainable Activities and China's Green Bond Endorsed Projects Catalogue, both of which include sector-specific criteria related to energy efficiency. Furthermore, the government — through the Energy Conservation Information System (SINERGI) — could provide a platform for financial institutions to register financing programs or products dedicated to energy efficiency. In collaboration with these institutions, the government can also develop guidelines for preparing financing proposals, aligned with both green taxonomy standards and each institution's internal financing criteria.

Figure 84.
Mechanism for enforcing the implementation of energy efficiency strategies in industry

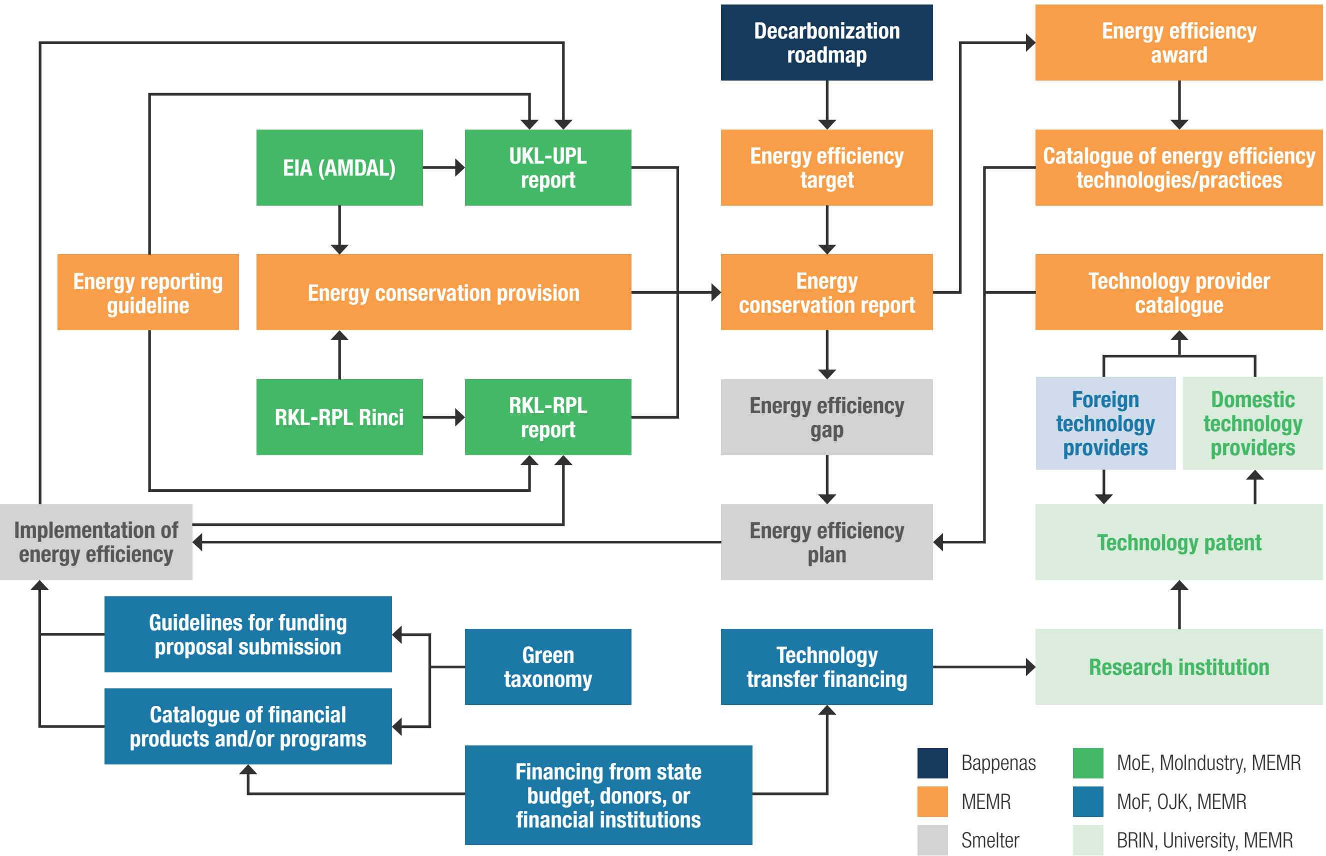


Table 17.
Policy framework to expand energy efficiency adoption in the nickel industry 2025-2045

<table>
<tr><th colspan="2">Policy Direction</th><td colspan="8">Expansion of energy efficiency adoption</td></tr>
<tr><th colspan="2">Objective</th><td colspan="8">Achieving smelter energy efficiency performance targets by providing technology and efficiency practices that are easily accessible and affordable</td></tr>
<tr><th rowspan="2">Challenge</th><th rowspan="2">Action Plan</th><th rowspan="2">Measure of Success</th><th colspan="5">Milestone</th><th rowspan="2">Lead Agency</th><th rowspan="2">Other Related Parties</th></tr>
<tr><th colspan="2">2025–2029</th><th>2030–2034</th><th>2035–2039</th><th>2040–2045</th></tr>
<tr><td rowspan="3">Limited alternative technologies and energy efficiency practices that are reliable, easily accessible and cheap, for the production process of RKEF Indonesia's smelter</td><td rowspan="3">Development of technical guidance and a catalogue of energy efficiency technologies and best practices that are easily accessible, and relevant and proven to be successful for RKEF smelters</td><td>The preparation of technical guidelines as well as a catalogue of technology and efficiency best practices that can be accessed by nickel smelter companies</td><td>Conducting a study of existing energy efficiency technology and practices by nickel smelters in Indonesia</td><td>Initiation of bilateral cooperation between countries related to energy efficiency technology transfer and/or purchase of patents related to RKEF nickel smelter energy efficiency technology and practices</td><td colspan="3">Publication of technical guidelines and updates of technology catalogues based on science and technology developments</td><td rowspan="3">Ministry of Energy and Mineral Resources</td><td rowspan="3">BRIN, universities, technology providers, nickel industry, state-owned enterprises</td></tr>
<tr><td rowspan="2">The development of the domestic efficiency technology supply industry</td><td colspan="2" rowspan="2">Initiation of a technology research institution, in collaboration with research institutions, universities, and nickel smelter company RKEF</td><td>Allocation of patent purchases for domestic energy efficiency technology research and development</td><td rowspan="2">Development of manufacturing industry and/or service design of domestic energy efficiency technology, initiated by SOEs</td><td rowspan="2">Development of manufacturing industry and/or service design of domestic energy efficiency technology, initiated by SOEs</td></tr>
<tr><td>Research activities that produce energy efficiency technology patents through technology research institutions</td></tr>
<tr><td rowspan="2">Limited availability of attractive financing schemes for energy efficiency measures</td><td rowspan="2">Development of funding submission guidelines for energy efficiency</td><td>Energy efficiency criteria in a green taxonomy comparable to international standards</td><td colspan="2">Establishment of energy efficiency criteria in green taxonomy and categorization guidelines of energy efficiency projects comparable to green taxonomy of other countries</td><td colspan="3">Mainstreaming of ESCO schemes to facilitate the adoption of energy efficiency strategies in the nickel industry</td><td rowspan="2">Ministry of Finance</td><td rowspan="2">OJK, ESDM, commercial banks, development banks, BPN, PT SMI, BRIN, nickel industry</td></tr>
<tr><td>Funding schemes and fiscal incentives for the development of biomass supply chains for the needs of reducing reductants are available</td><td>Budget reallocation for the development of technology research in the country</td><td>Mainstreaming of ESCO schemes to facilitate the adoption of energy efficiency strategies in the nickel industry</td><td colspan="3">Budget mobilization for technology research, efficiency technology industry development, and energy efficiency incentives, as well as monitoring the mix of green financing products/programs for energy efficiency from commercial banks and development banks in Indonesia</td></tr>
</table>

■ Challenge ■ Action Plan ■ Policy on technology and infrastructure ■ Policy on standard and regulation ■ Policy on financing and investment

5.6

ACCELERATION OF BIODIESEL ADOPTION

As much as 0.78% of emissions from the nickel industry are generated from the mobile combustion sources. The decarbonization strategy used is the substitution of vehicle fuel to biodiesel, then gradually increasing the mix. To realize this strategy, the amount and specifications of the biodiesel mix must be available according to decarbonization needs (availability), produced from sustainable sources (safeguard), and affordable (affordable).

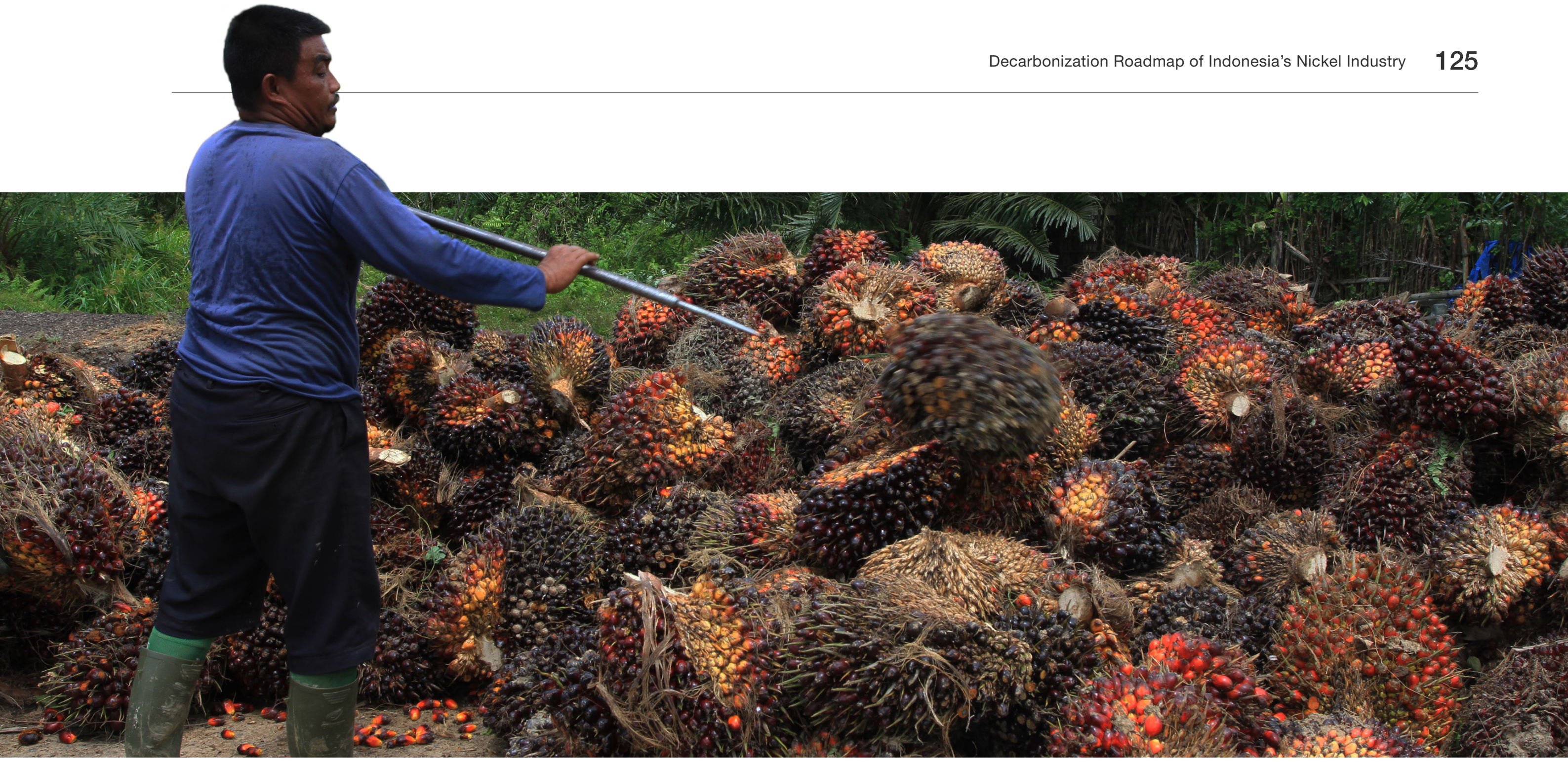
The use of biodiesel is one of the most mature decarbonization alternatives in Indonesia. Since 2015, the government has mandated the use of biodiesel in stages through the Minister of Energy and Mineral Resources Regulation No. 12 of 2015. In the regulation, the government targets the biodiesel mix to reach 30% in fuel oil by January 2025. In reality, the mix has reached 35% (B35) in 2024 and increased again to 40% (B40) in 2025. The government has revoked the Minister of Energy and Mineral Resources Regulation No. 12 of 2025 and replaced it with the Minister of Energy and Mineral Resources Regulation No. 4 of 2025, which no longer details the stages of the level of biodiesel utilization. Thus, the mandate for the use of biodiesel will be determined through a ministerial decree.

In terms of availability, the absence of medium- or long-term targets related to the phasing of biodiesel utilization rates can cause uncertainty. This is because the decarbonization of the nickel industry requires increasing the biodiesel mix at least every five years until 2045. Therefore, it is important to understand the potential gap that will occur in the future as shown in the following Table 19.

Table 18.
Comparison of biodiesel requirements under the government target and the decarbonization scenario

	2025		2030		2035		2040		2045	
	Blending rate	**Volume** (million litres)	**Blending rate**	**Volume** (million litres)	**Blending rate**	**Volume** (million litres)	**Blending rate**	**Volume** (million litres)	**Blending rate**	**Volume** (million litres)
Government target	B40	8,070	B40*	8,070*	B40*	8,070*	B40*	8,070*	B40*	8,070*
The decarbonization needs of the nickel industry	B30	274.8	B40	440.4	B50	550.5	B60	660.6	B70	770.7
Status	Fulfilled		Fulfilled		Unmet mix		Unmet mix		Unmet mix	

) The figure is assumed to be the same as the previous year because there has been no publication of the latest MER plan after 2025.



Based on the table above, the nickel industry's demand in 2025 accounts for only 3% of the national biodiesel production capacity. Therefore, the national production capacity is more than sufficient to meet the needs of the nickel industry. The key issue, however, is the absence of a formal medium- to long-term plan outlining the phasing of the biodiesel mix and production beyond 2025. To ensure biodiesel availability, alignment of targets and demand certainty must be strengthened. First, the government could issue a phased mandatory minimum biodiesel utilization plan that aligns with the Ambitious Scenario presented in this roadmap. This should be accompanied by the acceleration of research and piloting efforts to increase the biodiesel blend ratio. Second, the establishment of off-take agreements between nickel industry players and state-owned energy enterprises (SOEs) is recommended, in order to secure a committed allocation of produced biodiesel.

At the same time, if it is assumed that the entire volume of biodiesel produced already has specific offtakers, we see a potential strategy in the reallocation of national biodiesel export quotas. Currently, 27.4 million litres of biodiesel are exported. By reallocating this exported volume to the domestic market, an additional 743 million litres of biodiesel would still be required to meet projected needs.

From a safeguard perspective, environmental concerns associated with biodiesel are similar to those of bioreductants (as discussed in Subsection 5.3). Industry stakeholders are unwilling to use feedstocks derived from sources that contribute to deforestation or high land-use change emissions. Therefore, biodiesel would also benefit from one of the proposed strategies in that subsection, namely the establishment of a “National Standard for Sustainable Biomass.” A variety of biomass-derived products — including biodiesel, bioreductants, and biogas — can be classified as sustainable only when the feedstocks are sustainably produced from the outset and processed using clean technologies. Finally, from an affordability standpoint, the increased biodiesel blend has driven up the price of B40 from approximately IDR 13,000 to IDR 14,500–15,000 per litre, primarily due to the rising cost of FAME (Fatty Acid Methyl Ester). This has raised concerns, especially since the industry — along with hotels, mining, and plantations — belongs to the non-PSO (non-public service obligation) group, which does not receive subsidies. Through the Market Index Price (MIP) mechanism, the government needs to ensure that increased blending levels do not cause excessive price hikes, particularly as the Ambitious Scenario anticipates a 10% biodiesel price increase every five years. As an alternative strategy, the adoption of hydrogen-powered fuel cell vehicles may be considered. However, despite their near-zero emissions, the costs remain prohibitively high.

Table 19.
Policy framework to accelerate the biodiesel adoption in nickel industry 2025-2045

Policy Direction	**Acceleration of biodiesel adoption**
Objective	**Biodiesel to support the nickel industry's decarbonization needs is available in the required volumes and blend specifications, produced from sustainable feedstocks, and offered at an affordable cost.**

Challenge	Action Plan	Measure of Success	Milestone				Lead Agency	Other Related Parties
			2025–2029	2030–2034	2035–2039	2040–2045		
Unclear pathway for national biodiesel development	Regulatory reform to provide a national biodiesel mix target for 2025-2045	The national biodiesel development plan for 2025-2045 is available and align with the decarbonization needs of the nickel industry	The fourth amendment to the Minister of Energy and Mineral Resources Regulation No. 12 of 2015 to add a biodiesel mix target plan from 2025-2045 (previously only until 2025)	Biodiesel mix target to B40	Biodiesel mix target to B50	Biodiesel mix target to B60-B70	Ministry of Energy and Mineral Resources	Pertamina
The national biodiesel production volume is sufficient for the decarbonization needs of the nickel industry, but there is no certainty of use by the nickel industry	Allocation of national biodiesel production volume for the nickel industry	Available allocation and distribution of biodiesel to the nickel industry	Signing of medium-long term off-take agreements	Biodiesel is used by industry				
Setting environmental standards for biomass/ biodiesel	National standards (related to environmental aspects) for biodiesel/biomass are available	Issuance of national standards on sustainable biomass that are in line with international standards (including emission intensity, traceability, obligation to implement sustainable land management practices)	Implementation of periodic certification and evaluation	Pelaksanaan sertifikasi dan evaluasi berkala			Ministry of Energy and Mineral Resources, Ministry of Industry	BSN, LSPro
The rising price of biodiesel, in line with the increasing blend ratio, has put additional pressure on operating costs	Escort of the Market Index Price (MIP) for biodiesel	The increase in biodiesel prices is still in the affordable range for the industry	The implementation of a study on how to maintain the industry's superiority and interest in biodiesel amid rising prices along with an increase in its net feedstock mix	Implementation of study recommendations			Ministry of Energy and Mineral Resources, Ministry of Finance	BPDP, Pertamina
			Continue the production of biodiesel from the palm oil export levy managed by BPDP					

■ Challenge ■ Action Plan ■ Policy on technology and infrastructure ■ Policy on standard and regulation ■ Policy on financing and investment

5.7

IMPROVEMENT OF DECARBONIZATION GOVERNANCE SYSTEM

After identifying the range of GHG emission sources associated with nickel industry activities and outlining the corresponding decarbonization strategies, the most critical next step is to ensure effective implementation on the ground. This requires: 1) A nickel industry decarbonization governance system supported by an adequate regulatory and implementation infrastructure — including, for example, data platforms and institutional arrangements (i.e., infrastructure and regulatory framework); and 2) A set of supporting instruments designed to standardize and promote compliance with the governance system — such as a GHG emission calculation methodology specific to the nickel industry, decarbonization performance standards, and an incentive/disincentive mechanism.

It is important to note that the nickel industry produces a variety of environmental externalities ranging from liquid waste, solid waste, to land damage, and GHG emissions are just one of these externalities. In contrast to other environmental externalities that have been recognized for a long time and have a mature centralized governance system under the auspices of the Ministry of Environment, GHG emissions only began to be recognized after the ratification of the Paris Agreement in 2015 so that the governance system is still quite sporadic. To get an idea of the difference in the maturity level of the governance system, let's look at the following **Figure 85**.

Figure 85.

Regulations related to environmental impact management of nickel industry activities in Indonesia

🟩 Mandatory, with sanction 🟧 Mandatory, limited scope, with incentive 🟦 Mandatory, but no sanction for incompliance 🟪 Voluntary

	Impact Accounting	Target Setting	Strategy Making		Reporting		Rating
	Requires industries to identify the sources and potential environmental impacts of their activities.	Establishes environmental impact thresholds that must not be exceeded, or reduction targets that industries are required to achieve.	Defines the environmental impact reduction strategies that industries must implement and/or requires industries to prepare corresponding action plans.		Requires the reporting of progress on the implementation of environmental impact reduction strategies.		Assesses the performance and outcomes of the implemented environmental impact reduction strategies.
Environmental management							
Ministry of Environment (all industry)							
Water pollution	**Government Regulation No. 22 of 2021 – Environmental Impact Assessment (AMDAL)** Includes identification of activities that may generate: • Water pollution • Erosion Solid waste • Hazardous and toxic waste (B3 waste) • Land degradation • Air pollution	**Minister of Environment Regulation (PermenLH) No. 9/2006** Effluent standards for mining and nickel processing industries		**Government Regulation (PP) No. 22/2021 – Environmental Management and Monitoring Plan (RKL-RPL)** Requires industries to include plans to: • Treat wastewater (e.g., WWTP • Minimize erosion potential • Manage non-hazardous waste (e.g., reduction, reuse, recycling) • Manage hazardous waste (e.g., storage) • Prevent land degradation • Control air pollutants (e.g., CEMS)	**PP No. 22/2021 – RKL-RPL Report** environmental externality management plans. Submitted to MoEF, Provincial, and Local Governments.	**PROPER - compliance** Reports progress on all environmental externality management activities. Submitted to MoEF, PROPER Council, and made public.	**PROPER - compliance** Assesses outcomes of environmental management.
Watershed			**Minister of Environment and Forestry Regulation (PermenLHK) No. 59/2019** Mandates rehabilitation in river basins within operational areas				
Non-hazardous waste contamination			**PermenLHK No. 19/2021** Establishes mechanisms for managing slag as nickel industry by-products				
Hazardous waste contamination		**PermenLHK No. 6/2021** Hazardous and toxic waste (B3) quality standards for industries (including nickel)	**PermenLHK No. 6/2021** Guidelines for B3 waste characterization (TCLP test) and management procedures.				
Land degradation			**Government Regulation (PP) No. 78/2010** Requires post-mining reclamation activities **PP No. 23/2021** Obligates IPPKH (Borrow-Use Forest Permit) holders to conduct reclamation and rehabilitation after mining operations conclude				
Air pollution		**PermenLH No. 4/2004** Emission standards for stationary sources in mining industries (including nickel). **PermenLH No. 15/2009** Emission standards for thermal power plants (e.g., coal-fired power plants).					
Ministry of Energy and Mineral Resources (specifically for nickel mining and integrated smelter)							
Water pollution	**MEMR Regulation (PermenESDM) No. 26 of 2018 & Ministerial Decree (KepmenESDM) No. 1827K/2018** Include the identification of activities that may generate: • Water pollution • Land degradation		**PermenESDM No. 26 of 2018 & KepmenESDM No. 1827K/2018** Require the preparation of environmental management documents containing plans for: • Wastewater management • Post-mining land management • Overburden management		**PermenESDM No. 26 of 2018 & KepmenESDM No. 1827K/2018** Require the preparation of environmental reports that include progress on: • Wastewater management • Post-mining land management • Overburden managemen		
Land degradation							

🟩 Mandatory, with sanction 🟧 Mandatory, limited scope, with incentive 🟦 Mandatory, but no sanction for incompliance 🟪 Voluntary

	Impact Accounting Requires industries to identify the sources and potential environmental impacts of their activities.	**Target Setting** Establishes environmental impact thresholds that must not be exceeded, or reduction targets that industries are required to achieve.	**Strategy Making** Defines the environmental impact reduction strategies that industries must implement and/or requires industries to prepare corresponding action plans.	**Reporting** Requires the reporting of progress on the implementation of environmental impact reduction strategies.	**Rating** Assesses the performance and outcomes of the implemented environmental impact reduction strategies.
GHG Emission Management					
Overarching Regulation					
Climate Change (GHG Emissions)	🟩 **Presidential Regulation No. 98 of 2021 on Carbon Economic Value and Minister of Environment and Forestry Regulation No. 12 of 2024** Provide the basis for managing and reducing national GHG emissions across all subsectors to achieve NDC targets. Further regulations are needed to contextualize these provisions at the industry level.				
Ministry of Industry					
Climate Change (GHG Emissions)	🟦 **Minister of Industry Regulation No. 2 of 2019, Ministerial Circular No. 2 of 2025 (SIINAS Platform)** Mandates industries to submit GHG emission data covering: • Industrial process and energy use • Energy activity data • Industrial waste activity data			🟦 **Minister of Industry Regulation No. 2 of 2019, Ministerial Circular Letter No. 2 of 2025 (SIINAS Platform)** Requires reporting on GHG emission reduction activities, including: • Energy sector – renewable energy use (e.g., solar PV, wind, captive biomass, RDF, liquefied natural gas, sludge oil) • Waste sector – B3 waste management methods	
Ministry of Energy and Mineral Resources					
Climate Change (GHG Emissions)	🟧 **POME Platform** Mandates industries to submit GHG emission data covering: • Energy use data • Electricity generation activity data 🟧 **APPLE-GATRIK Platform** Requires the inventory and reporting of activity data for GHG emission calculation, including: • Energy emission activity data (for captive power plants)	🟧 **Presidential Regulation No. 12 of 2022** Mandates captive CFPP to reduce emissions by 35% compared to the 2022 level and phase out by 2050	🟧 **Government Regulation No. 33 of 2023** Requires the implementation of energy management for industries consuming ≥4,000 TOE 🟧 **Minister of Energy and Mineral Resources Regulation No. 8 of 2025** Mandates industries to appoint energy managers, conduct energy audits, implement recommendations, and report outcomes	🟧 **POME Platform** Requires reporting of GHG emission reduction activities, including: • Energy sector – conservation and efficiency • Energy sector – renewable energy (solar PV, wind, captive biomass, biofuel, etc.) • Energy sector – REC implementation 🟧 **APPLE-GATRIK Platform** Reports GHG emission reduction activities, including: • Energy sector – use of renewable energy (solar PV, wind, captive hydropower, biofuel, etc.)	
Ministry of Environment					
Climate Change (GHG Emissions)				🟪 **PROPER – beyond compliance** Reports progress on GHG emission reduction plans. Submitted to MoEF, the PROPER Advisory Board, and the public.	🟪 **PROPER – beyond compliance** Evaluates GHG emission reduction performance.

Environmental impact management from industrial activities involves five key stages: impact accounting, target setting, strategy making, reporting, and rating. In other environmental externality governance systems under the Ministry of Environment, environmental impacts are identified through the EIA, the management plan/strategy is described in the RKL RPL, and the progress of its management is reported and assessed through the RKL RPL and PROPER Reports. Environmental impact management performance standards are regulated through a variety of regulations related to quality standards (Government Regulation, Ministerial Regulation, and Regional Regulation) so that all environmental externality management strategies have clear targets. As a follow-up, industries that do not make an EIA will not be issued environmental permits and industries that do not comply with quality standards may be threatened with their business licenses revoked. There is an additional governance system under the Ministry of Energy and Mineral Resources, but this is specifically for the nickel ore mining industry as well as the integrated nickel ore mining and processing industry.

On the other hand, GHG emissions management in the industrial sector is currently governed by three unintegrated and fragmented systems, each under a different ministry. This fragmentation stems from two main factors: 1) The industry produces three types of emissions whose authority is spread across the three ministries – energy sector emissions under the authority of the Ministry of Energy and Mineral Resources, IPPU under the Ministry of Industry (Kemenperin), and waste under the Ministry of Environment; and 2) MoE Regulation No. 12 of 2024 which regulates the procedures for implementing new NDCs that come out after the three systems are running. As a result, several key challenges have emerged. First, GHG emission data and emission reduction activity data reported across systems tend to be redundant and partial. For example, both SIINas (by Ministry of Industry) and APPLE-GATRIK (by Minister of Energy and Mineral Resources) request energy-related GHG emission data. However, at the same time, the reporting format in SIINas for IPPU and waste sector emissions does not yet fully accommodate all potential emission sources from the nickel industry (see explanation in **Table 20**). Furthermore, in the PROPER program, reporting on GHG emission components is categorized as "beyond compliance". This means that a company can still achieve a “Blue PROPER” rating — and thereby secure its business permit — without managing its GHG emissions at all.

The second challenge lies in the fact that current decarbonization targets and standards remain limited to power sector, while many other decarbonization actions are potentially applicable but have yet to be formally recognized or encouraged. To address this, it is necessary to establish GHG emission standards for nickel products, in order to drive a more comprehensive approach to industrial decarbonization. One of the instruments that can be used is the Green Industry Standard (SIH) issued by the Ministry of Industry. However, currently there is no SIH for the nickel industry, so further preparation is needed. Regarding the decarbonization target instrument, the Ministry of Industry is preparing a decarbonization roadmap for 9 industrial subsectors that will contain cross-sector GHG emission reduction pathways that must be achieved by the industry and priority decarbonization strategies that need to be implemented. These nine subsectors include the metals subsector that oversees nickel, so it is important to align this roadmap with the SIH and the roadmap.

The third challenge is that there are no sanctions for non-compliance in managing GHG emissions and the lack of incentives to decarbonise. The only incentive for the implementation of decarbonization activities that has been concretely provided is from the Minister of Energy and Mineral Resources Regulation No. 8 of 2025 which gives the industry the right to receive training, certification, and funding for energy audits to encourage the implementation of energy efficiency; as well as the opportunity to be awarded a green or gold PROPER if it includes a GHG emission component in the PROPER report. In fact, there are at least two other policies that have the opportunity to bring additional incentives for the decarbonization of the nickel industry, namely 1) carbon pricing policy – specifically the acceleration of the implementation of phase two cap-and-trade under the Ministry of Energy and Mineral Resources for the electricity sub-sector which is planned to include captive power plants; and 2) Government Regulation No. 20 of 2024 concerning Industrial Areas which states that

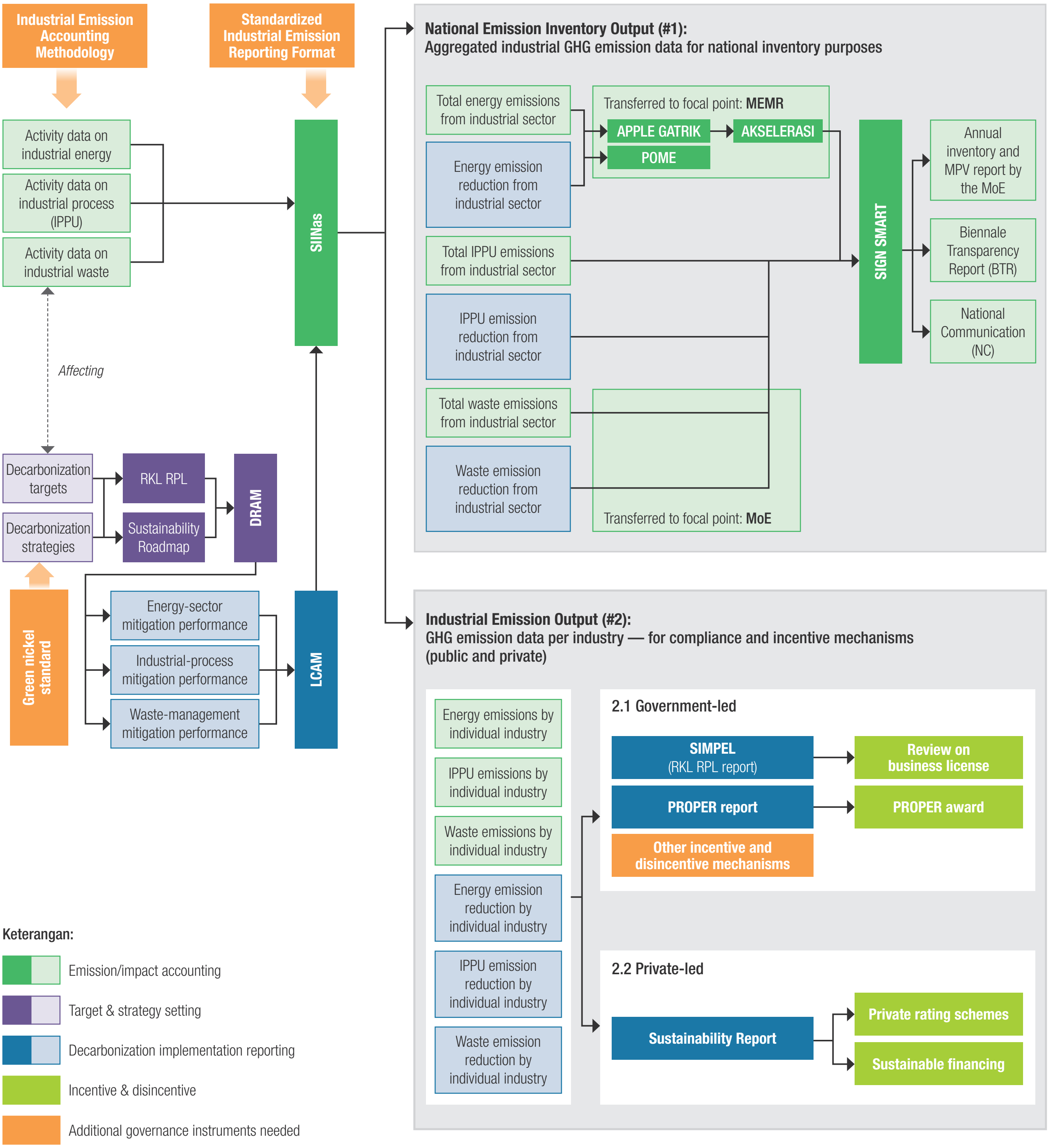
industrial estates that can utilize natural resources efficiently, environmentally friendly, and sustainable are entitled to receive fiscal and non-fiscal facilities from the central and regional governments, including the provision of land, training, and the construction of physical infrastructure. This opportunity needs to be realized immediately, especially considering that many of the nickel industries are located in industrial estates and have captive power plants.

To answer these challenges, first, it is necessary to integrate a cross-sectoral emission and decarbonization governance system. In the context of the nickel industry, the SIINas platform can be used as the main door for the industry to report all GHG emission data, including emission activity data and data from the implementation of mitigation actions. SIINas will then have two types of data processing results that are adjusted to the next data distribution purpose, namely:

- **National GHG emission inventory.** The data collected are total GHG emission data and total industrial GHG emission reduction achievements at the national level in aggregate for each sector, namely energy, IPPU, and waste. The data is then channelled to the Minister of Energy and Mineral Resources data platform as the focal point of the energy sector, the MoE data platform as the focal point of the waste sector, and finally integrated in SIGN-SMART;
- **The interest in obtaining incentives and/or compliance with other reporting.** The data collected are total GHG emission data and total GHG emission reduction achievements per industry which are adjusted to the data framework requested by each mechanism. Examples of mechanisms initiated by the government that fall into this category are the reporting of the RPL RKL, proper, the NEK mechanism (specifically carbon trading), and other mechanisms that have developed over time. Meanwhile, an example of a mechanism initiated by the private sector that falls into this category is the creation of a Sustainability Report.

The proposal for renewal of the governance system design is explained in **Figure 86.**

Figure 86.
Proposal to improve the governance of the decarbonization of the nickel industry in Indonesia



Second, a set of supporting instruments is required to standardize and promote compliance with the implementation of the decarbonization governance system. There are three key instruments that need to be in place, the first of which is:

1) Methodology for inventorying GHG emissions of the nickel industry

To produce the two types of data processing as described earlier, it is necessary to standardize the emission calculation methodology, publish emission calculation and reporting guidelines, and update the emission data reporting format for the nickel industry so that the data collected in SIINas is in line with the needs of other platforms. Full data on GHG emission activity data that needs to be reported by industry is described in **Table 20** of the "Ideal Conditions" section. In addition, considering that data is shared across ministries, strict SOPs for data protection and management are needed.

Table 20.
Proposal to improve the inventory of GHG emissions in the nickel industry in Indonesia

No.	Data Request	Ideal Conditions	Existing Conditions			
		Integration system	System 1: SIINas	System 2.1: POME	System 2.2: APPLE GATRIK	System 3: PROPER
1	**Energy sector**					
1.1	**Fuel consumption at stationary sources – for captive power plants**					
	Fossil energy consumption (e.g. coal, natural gas, oil)	Included	Included	Not	Included	Depends on the industry
	Consumption of renewable energy (e.g. solar, wind, hydro, biomass)	Included	Included	No	Included	
1.2	**Fuel consumption at stationary sources – other than for captive power plants**					
	Fossil energy consumption (e.g. coal, natural gas, oil)	Included	Included	Included	No	Depends on the industry
	Consumption of renewable energy (e.g. solar, wind, hydro, biomass)	Included	Included	Included	No	
1.3	**Energy consumption at mobile sources**					
	Consumption of fossil energy (e.g. diesel, gasoline)	Included	Included	Included	No	Depends on the industry
	Consumption of renewable energy (e.g. biodiesel)	Included	Included	Included	No	
1.4	**Energy purchase**					
	Purchase of electricity from fossil energy (e.g. coal-fired power plants, PLTG)	Included	Included	Included	No	Depends on the industry
	Purchase of electricity from renewable energy (e.g. PLTA, PLTB, PLTS)	Included	Included	Included	No	
2	**IPPU Sector**					
	Consumption of input materials (e.g. feedstock, lubricants, etc.)	Included	Partially, feedstock is included but the input column is not separated from energy activity data	No	No	Depends on the industry
	Total output products (e.g. FeNi/NPI, nickel matte, slag)	Included	Included, but not limited to, prone to missing	No	No	
3	**Waste sector**					
	Solid waste generation (e.g. tailings)	Included	Included, but not limited to, prone to missing	No	No	Depends on the industry
	Solid waste treatment methods	Included	Partial, B3 only	No	No	
	Liquid waste generation (e.g. mine runoff)	Included	Included, but not limited to, prone to missing	No	No	
	Liquid waste treatment methods	Included	No	No	No	
4	**Land sector**					
	Cleared land area	Included	Not	No	No	Depends on the industry
	Planted land area	Included	Not	Not	Not	

2) Reference for setting reduction targets and performance standards in the nickel industry

This roadmap is developed with the intention of serving as a reference framework for GHG emission reduction targets or performance standards within the nickel industry. To have legal authority, there are at least two possible enforcement models. The first is to ratify the roadmap into a regulation or ministerial decree, and the second is to ratify the roadmap into a stand-alone standard called the "Indonesian Green Nickel Standard". The Indonesian Green Nickel Standard is expected to function as a standard for the sustainability performance of the nickel industry, both in terms of environmental, social, and internal governance of the company. The environmental component of this standard needs to include criteria related to GHG emissions and the use of new and renewable energy that are prepared in accordance with the Ambitious Scenarios in this roadmap. In its implementation, the Indonesian Green Nickel Standard can also be translated into the Green Industry Standard (SIH) for the Nickel Industry under the Ministry of Industry. SIH is known for often adjusting the criteria with other regulations, so that companies can get certification with the parameters in this roadmap and the parameters in other applicable regulations. The translation of the reduction target reference into regulations, SIH, and/or other stand-alone standards is completely left to the government. The components of the standard and their correlation with applicable regulations are described in **Figure 87**.

Figure 87.
Recommended criteria of the Indonesian Green Nickel Standard

Key Provisions	Recommended Green Nickel Standard Criteria					Note
	25	30	35	40	45	
Total emission reductions in industry	0%	6.3%	38.3%	75.2%	81.1%	In line with the RPJPN
Emission intensity	105.2	96.2	65.8	30.7	23.5	
Per Decarbonization Strategy						
1. Adoption of clean electricity – Conventional and green hydrogen-based renewable energy used for clean electricity generation						
a. End of CFPP operation	2045					It is more ambitious than Presidential Regulation No. 112 of 2022 which targets the end of operation in 2050 and the target of reducing medium-term coal-fired power plant emissions at 35%
b. Total medium-term coal-fired power plant emission reduction	67.47%					
c. Percentage of renewable energy mix						
Cluster 1 – Hydro, wind, and solar power	0%	1.92%	29.51%	90.58%	98.43%	More ambitious than the on-grid clean electricity supply capacity listed in the 2024-2060 RUKN
Cluster 3 – Hydro, wind, and solar power	0%	2.34%	31.07%	90.32%	98.42%	
Cluster 2 – Hydro, wind, and solar power	0%	0.01%	0.82%	6.76%	12.81%	
Cluster 2 – Green hydrogen-based PLTG	0%	0.00%	6.07%	53.55%	66.85%	More ambitious than RUKN & PHAN
2. Substitution of coal-based reductant with bioreductant						
a. Percentage of bioreductant mixture						
Cluster 1	0%	10%	30%	75%	80%	
Cluster 2	0%	30%	80%	100%	100%	
Cluster 3	0%	10%	30%	75%	80%	

Key Provisions	Recommended Green Nickel Standard Criteria					Note
	25	30	35	40	45	
3. Average nickel content in ore input						
Grade	1.7%					
4. Substitution of coal fuel with LNG in rotary dryer and rotary kiln						
Cluster 1	0%	5%	15%	23%	23%	
Cluster 2	0%	30%	80%	100%	100%	
Cluster 3	0%	5%	15%	23%	23%	
5. Energy efficiency through waste heat recovery						
a. From electric furnace to rotary dryer	34%					In Government Regulation No. 33 of 2023 concerning Energy Conservation and Minister of Energy and Mineral Resources Regulation No. 8 of 2025 concerning Energy Management, new industries are encouraged to carry out energy efficiency activities but there is no minimum efficiency target that must be achieved
Future Plant (2026 onwards)	0%	100%	100%	100%	100%	
Existing Plant (as of 2025)	0%	50%	80%	80%	80%	
b. From rotary kiln to rotary dryer	14%					
Future Plant (2026 onwards)	0%	100%	100%	100%	100%	
Existing Plant (as of 2025)	0%	50%	80%	80%	80%	
c. From slag granulator to rotary dryer	20%					
Future Plant (2026 onwards)	0%	100%	100%	100%	100%	
Existing Plant (as of 2025)	0%	50%	75%	80%	80%	
6. Substitution of diesel in vehicles with biodiesel						
a. Percentage of biodiesel mix						
All clusters	B30	B40	B50	B60	B70	

3) Implementation of incentive and disincentive mechanisms to advance nickel industry decarbonization

This approach includes, namely market-based and non-market mechanisms. The market-based mechanism through the implementation of carbon pricing that covers the nickel industry, starting from the application of carbon trading in the off-grid/captive electricity subsector, then expanded to industrial subsectors, including nickel. The determination of the cap agreement (PTBAE-PU) for carbon trading is based on regulations or ministerial decrees that formalize the GHG emission reduction trajectory outlined in this roadmap. Thus, each strategy in the roadmap is required to have a methodology for calculating GHG emission reductions recognized by the Ministry of Environment, and the entire target setting and strategy making process must refer to the performance standards in the Indonesian Green Nickel Standard. Meanwhile, the non-market mechanism is implemented by promoting the development of green industrial estates, with nickel industrial parks tenants required to adopt certain green standards in order to qualify for fiscal and non-fiscal incentives. This is in line with Government Regulation No. 20 of 2024, which regulates the provision of incentives to industrial companies that implement efforts toward achieving green industry objectives.

Table 21.
Policy framework for improving national nickel decarbonization governance 2025-2045

Policy Direction	**Improvement of decarbonization governance system**
Objective	**The nickel decarbonization governance system is integrated and supported by adequate regulations, infrastructure, and instruments**

Challenge	Action Plan	Measure of Success	Milestone						Lead Agency	Other Related Parties
			2025-2029			2030–2034	2035–2039	2040–2045		
The current governance system for industrial decarbonization is fragmented, with multiple subsystems and platforms managed under different ministries	Improvement of the governance system for the decarbonization of the nickel industry	Integrated industrial decarbonization governance system and all its supporting instruments adopted	Design of reforms to strengthen governance for nickel industry decarbonization	Gradual adjustment of the regulation and governance infrastructure of the decarbonization of the nickel industry (e.g. updates on the SIINas platform)		Implementation of a mandatory decarbonization governance system for the nickel industry This includes: 1) Emission accounting: Refers to the methodology in the GHG emission inventory guide in the nickel industry, then reported to SIINas which already has a new industrial GHG emissions data reporting format. 2) Target setting and strategy making: Refers to the Ministerial Regulation or Ministerial Decree on the Nickel Industry Decarbonization Roadmap. At the same time, there is also SIH for the nickel industry/Green Nickel Industry Standard, as a certification mechanism that includes GHG emissions as an assessment parameter and other parameters in ESG. 3) Reporting: Done to SIINas, and can be followed up by appropriate and available incentive mechanisms.			Ministry of Industry, Ministry of Energy and Mineral Resources, Ministry of Environment	Nickel industry, academics, think tanks
The inventory of GHG emissions carried out in the nickel industry is not comprehensive	Preparation of instruments to support the governance of nickel decarbonization (1/2)	A guide containing methodologies for inventorying GHG emissions in the nickel industry is available	The preparation of a guide containing the methodology of GHG emission inventory in the nickel industry	The preparation of the GHG emission data reporting format according to the methodology as a material for updating the nickel industry decarbonization governance system						PERHAPI, APNI, academics, nickel industry, NGOs, trade partners, third party standard setters (IRMA, ICMM, etc.)
There is no performance standard for efforts to reduce GHG emissions in the nickel industry		Reference for reduction targets or performance standards for GHG emission reduction efforts in the nickel industry is available	The Nickel Industry Decarbonization Roadmap is formalized/ ratified into regulations or ministerial decrees	The preparation of the "Indonesian Green Nickel Standard" or "SIH for the Nickel Industry" (depending on the policy implementer) which adopts all targets and strategies in the roadmap, and is recognized by nickel buyers from domestic and international markets as a reference for the definition of low carbon nickel						
Lack of incentives for the implementation of decarbonization in industry (1/2)		Market-based incentive mechanism for the decarbonization of the nickel industry is available (carbon pricing)		The determination of PTBAE-PU for the nickel industry to: a. Emissions of the electricity subsector from captive power plants, by the Ministry of Energy and Mineral Resources. b. Emissions of the industrial subsector from activities that produce non-generation energy emissions, IPPU, and waste, by the Ministry of Industry PTBAE are made in line with the emission reduction trajectory in the regulation or decree of the minister, which is in line with the roadmap	All strategies included in the roadmap have a methodology for calculating GHG emission reductions that are recognized by the Ministry of Environment	Implementation of carbon trading involving the nickel industry for the electricity subsector (max. from 2030) and industrial subsectors (max. from 2034) Implementation and implementation of the results of the study on carbon tax				Academics, nickel industry, NGOs, consultants, LVV

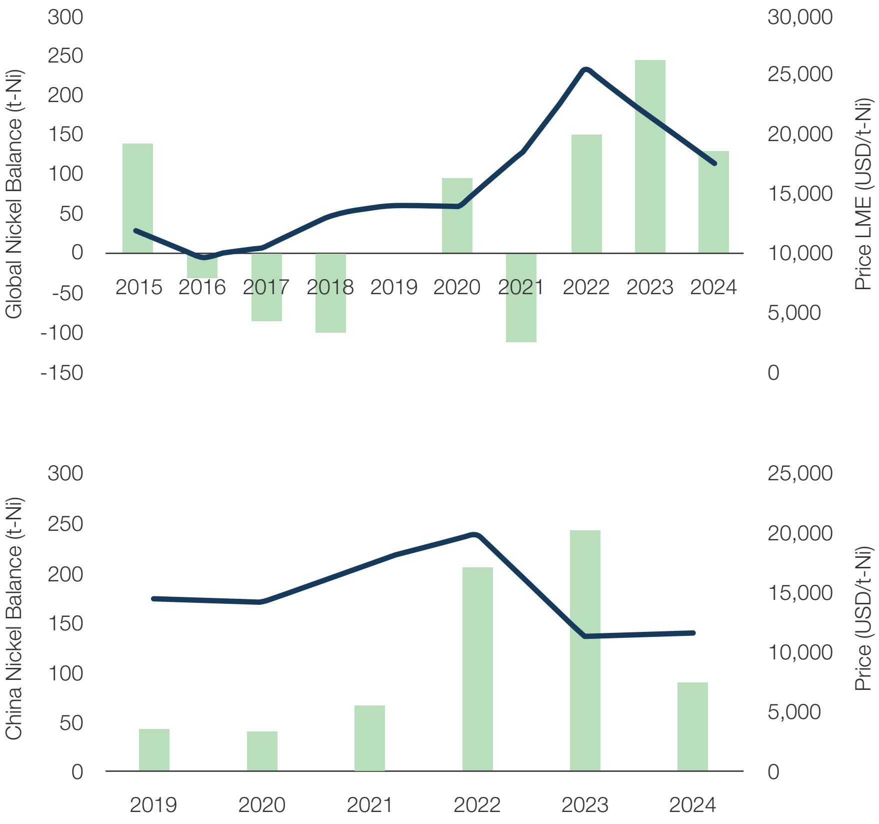
Challenge	Action Plan	Measure of Success	Milestone				Lead Agency	Other Related Parties
			2025–2029	2030–2034	2035–2039	2040–2045		
Lack of incentives for the implementation of decarbonization in industry (2/2)	Preparation of instruments to support the governance of nickel decarbonization (2/2)	Non market-based incentive mechanism for the decarbonization of the nickel industry is available	Mechanisms for providing fiscal and non-fiscal incentives from industrial estates for the nickel industry that decarbonise are available	Implementation of carbon trading involving the nickel industry for the electricity subsector (max. from 2030) and industrial subsectors (max. from 2034) Implementation and implementation of the results of the study on carbon tax			Ministry of Industry, Ministry of Energy and Mineral Resources, Ministry of Environment	Local government

■ Challenge ■ Action Plan 🟩 Policy on technology and infrastructure 🟦 Policy on standard and regulation 🟧 Policy on financing and investment

5.8

IMPLEMENTATION OF NICKEL PRICE CONTROL MECHANISM

Figure 88.
Global nickel balance and price dynamics

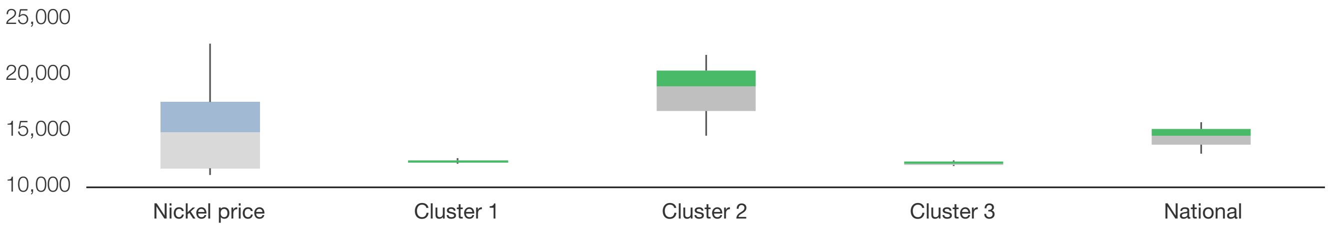


Based on historical nickel price data, there is a strong correlation pattern with a characteristic delay between the supply-demand equilibrium of nickel and its impact on price movements. Historical data shows that oversupply conditions tend to lead to nickel price declines in the following year, driven by market corrections. In addition to nickel market balance, other factors may also influence price trends, including exchange rate fluctuations between countries, import and export tariffs, and direct negotiations between sellers and buyers. Furthermore, inter-country policy decisions can affect market sentiment, which in turn may impact the actual transaction prices of nickel.

The persistence of oversupply conditions since 2022 has the potential to continue to correct nickel prices at low levels. Meanwhile, the price of nickel products is an important component in ensuring that there is enough margin for nickel producers to decarbonise while maintaining the financial sustainability of their business. Based on historical data, variations in nickel prices and variations in raw material prices for decarbonised nickel production will greatly determine a company's margin profile. **Figure 88** shows the comparison of the production costs of one ton of nickel in each study area under non-intervention conditions against nickel prices and raw material prices. On average, a positive margin can be generated for smelters in Cluster 1 up to 23.8% and Cluster 3 up to 25.2%. On the other hand, smelters in Cluster 2 will find a negative margin of up to -37.7% due to the significant use of hydrogen as a source of energy for power generation. Without price intervention, the market price of hydrogen commodities is very expensive compared to other types of energy.

Figure 89.
Total nickel production costs per cluster without raw material price intervention compared to the average nickel price in the market

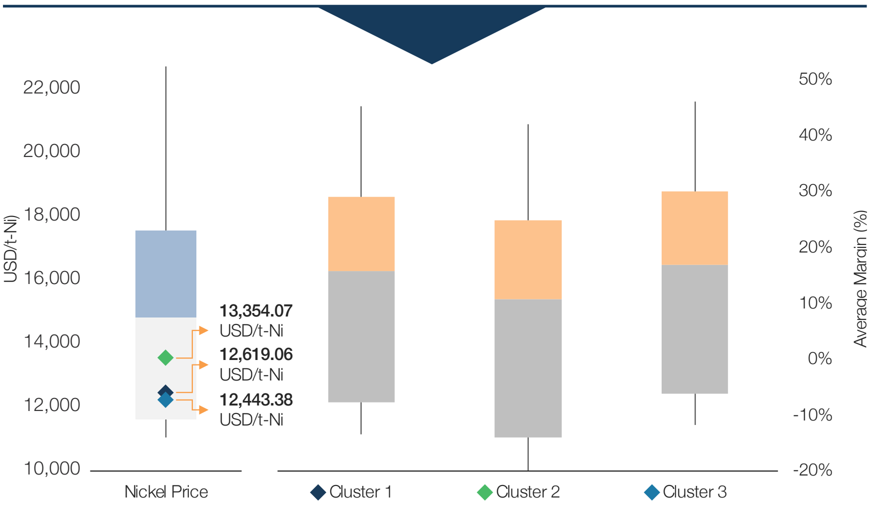
USD per ton of nickel



The raw material price recommendations aim to keep the average company margins in the three clusters above 10% while implementing decarbonization actions in line with the targets in the Ambitious Scenario. If policy intervention is carried out to ensure that prices are in accordance with the recommendations in **Figure 90**, it is likely that companies will be able to get a margin of 10%. This margin level is considered rational for the nickel industry to operate based on data on production costs and selling prices of several NPI producing companies in 2023 and 2024. However, it is still necessary to underline that the margin calculation uses the average price of the NPI reaching 14,847.13 USD/t-Ni. Thus, the success of this intervention cannot be separated from the implementation of nickel supply and price control policies.

Figure 90.
Projected impact of raw material price interventions on the size of margins per cluster

Material Input		Average Price (historical)	Maximum Price (historical)	Minimum Price (historical)	Recommended Price
Electricity	On grid electricity	6.84 USDc/kWh			7.82 USDc/kWh
	Solar PV (Cluster 2)	9.38 USDc/kWh	17.64 USDc/kWh	6.13 USDc/kWh	11.31 USDc/kWh
	Wind (Cluster 2)	7.47 USDc/kWh	18.77 USDc/kWh	3.92 USDc/kWh	13.10 USDc/kWh
	Hydropower (Cluster 2)	4.15 USDc/kWh	13.16 USDc/kWh	1.98 USDc/kWh	5.39 USDc/kWh
Hydrogen		2.50 USD/kg	2.00 USD/kg	5.45 USD/kg	0.78 USD/kg
LNG		12.81 USD/mmbtu	23.73 USD/mmbtu	5.88 USD/mmbtu	6.50 USD/mmbtu
Sub-bituminous		55.43 USD/ton	58.56 USD/ton	50.41 USD/ton	55.43 USD/ton
Biomass		133 USD/ton	168 USD/ton	70 USD/ton (DMO)	140 USD/ton
Anthracite		123.38 USD/ton	139.80 USD/ton	109.77 USD/ton	123.38 USD/ton
100% Biodiesel		1.159 USD/Liter	1.168 USD/Liter	1.153 USD/Liter	1.159 USD/Liter
100% IDO		1.132 USD/Liter	1.141 USD/Liter	1.126 USD/Liter	1.132 USD/Liter



To achieve this, a mechanism to control the supply and demand of NPI is required, as it is considered a parameter that can be concretely influenced and has shown significant historical impact on nickel prices (see **Figure 91**). Several control measures can be implemented through interventions such as:

1.

Supply and demand control mechanism through the moratorium on RKEF smelter construction

The Indonesian government in 2025 has issued a statement regarding the plan to carry out a moratorium on the construction of the RKEF smelter. This policy is expected to have a clear legal basis to ensure its implementation and strengthen market sentiment in increasing nickel prices. This policy can then be reviewed periodically with policy adjustments depending on the development plan of the stainless steel industry in Indonesia.

2.

Supply and demand control mechanism through the creation of the national metal exchange

One of the important components of nickel trading is the certainty of a decent price for both sellers and buyers. This decent pricing can be used as a base price in negotiations between sellers and buyers. The exchange is here to mediate the negotiation process by acting as a centre for consolidating the availability of products and their needs. Indonesia as the world's largest producer of class II nickel has an important position that can then play its role as a price controller. Until now, the condition of nickel prices in Indonesia is based on supply and demand conditions in countries that manage the exchange. By forming a domestic nickel exchange, the benchmark nickel price can be influenced mainly by the condition of nickel supply and demand equilibrium in Indonesia. This exchange can be an important accelerator in the domestic nickel trade.

3.

Supply and demand control mechanism through the establishment of state-owned enterprises for nickel trading and the production of high grade nickel matte

To be able to control nickel prices directly, the government can form SOEs with a focus on business areas engaged in the trade of NPI, FeNi, and Low Grade Nickel Matte, as well as large-scale production of high-grade nickel matte. This SOE is expected to ensure the purchase of the class II nickel product at a stable price under fluctuating market price conditions. When the nickel price is lower than the price set, the SOE can increase the production of high-grade nickel matte that can be sold in the EV market where the price is relatively higher on average. In addition, these SOEs can also store a portion that cannot be sold at a higher price in the EV market, to be sold when the nickel price is higher. The government can collaborate with Danantara as an investment management institution in the formation of this SOE.

4.

Supply and demand control mechanism through accelerating the development of the stainless steel industry in Indonesia

To maintain the balance of supply and demand, control of demand can be carried out through intensification of production activities that require NPI and FeNi. For this reason, the acceleration of the development of the stainless steel industry has a very important role in maintaining nickel prices and providing more flexibility to the nickel trading exchanges and state-owned enterprises to have an effect on flattening out nickel prices. Various incentive mechanisms for investors who build their stainless steel factories in Indonesia need to be further studied and considered for implementation. By taking the good steps that the government has taken in growing the class II nickel industry in Indonesia, the acceleration of the development of the stainless steel industry in Indonesia is expected to be achieved. The roadmap for nickel downstream from nickel ore to ready-to-use products needs to be developed and given a legal basis, to provide certainty to investors in executing their plans in Indonesia.

The establishment of SOEs engaged in stainless steel production is also considered important as a seeding project that can drive the acceleration of the development of the stainless steel industry in Indonesia. These SOEs can also become vehicle parties from the nickel exchange and state-owned nickel trading SOEs in an effort to control nickel prices in Indonesia. The government can collaborate with Danantara as an investment management institution in the formation of this SOE. The production plan can be controlled to provide a flattening out effect on the conditions of nickel supply and demand imbalance. Further studies on business and financial models are needed to ensure that companies can remain profitable, supported by stable nickel prices—for instance, the NPI 2023 average of USD 14,847.13 per ton of nickel.

5.

Supply and demand control mechanisms through green certification for domestic end-user industries such as the steel sector, building, transportation sector, household appliances, and manufacturing

To ensure the availability of demand for low-carbon nickel products, a green certification mechanism is needed that is applied to nickel and stainless steel end users in the country. The building, transportation, household appliance production, and manufacturing sectors can be targeted because they have a demand for stainless steel. The use of materials with carbon embodied nickel intensity that are in accordance with this roadmap needs to be used as a criterion in the green certification. The voluntary mechanism can be used as a first step with the need for an incentive mechanism in it. Gradually, this green certification can be made mandatory.

Infrastructure projects can be used as the main vehicle in encouraging the use of this green certification. In addition, the government can also use infrastructure projects to drive the demand for stainless steel in Indonesia, which then has implications for the flattening out effect of nickel prices in Indonesia.

6.

Price control mechanism through the establishment of Green Nickel Standard and internationally recognized independent certification bodies.

To facilitate the trading process of nickel products that implement this decarbonization roadmap, as well as to emphasize the value proposition of these products, it is necessary to establish a green nickel standard that is in accordance with market expectations. These standards also need to be aligned with the green finance taxonomy as well as supply chain-based ESG policies in nickel-importing countries. For nickel buyer companies, the existence of the green nickel standard and its certification can cut the supply chain due diligence stages that take their time and resources. This is because nickel buyer companies will be able to use the certification as a guarantee that nickel has been produced according to the provisions and there is no longer a need to conduct a supply chain due diligence assessment study from the beginning.

Various green nickel advocacy in international forums related to trade and climate, as well as the negotiation of trade cooperation agreements with countries that prioritize ESG aspects are expected to be carried out by the government. The establishment of associations/chambers of commerce involving importing countries can be carried out with the ultimate goal of creating a mutually recognized green nickel standard. Price certainty with an average minimum of 14,873.13 USD/TJ and nickel demand certainty between countries are expected to be agreed in line with the agreement on green nickel standards.

Figure 91.
Mechanisms to control the price of nickel in the market

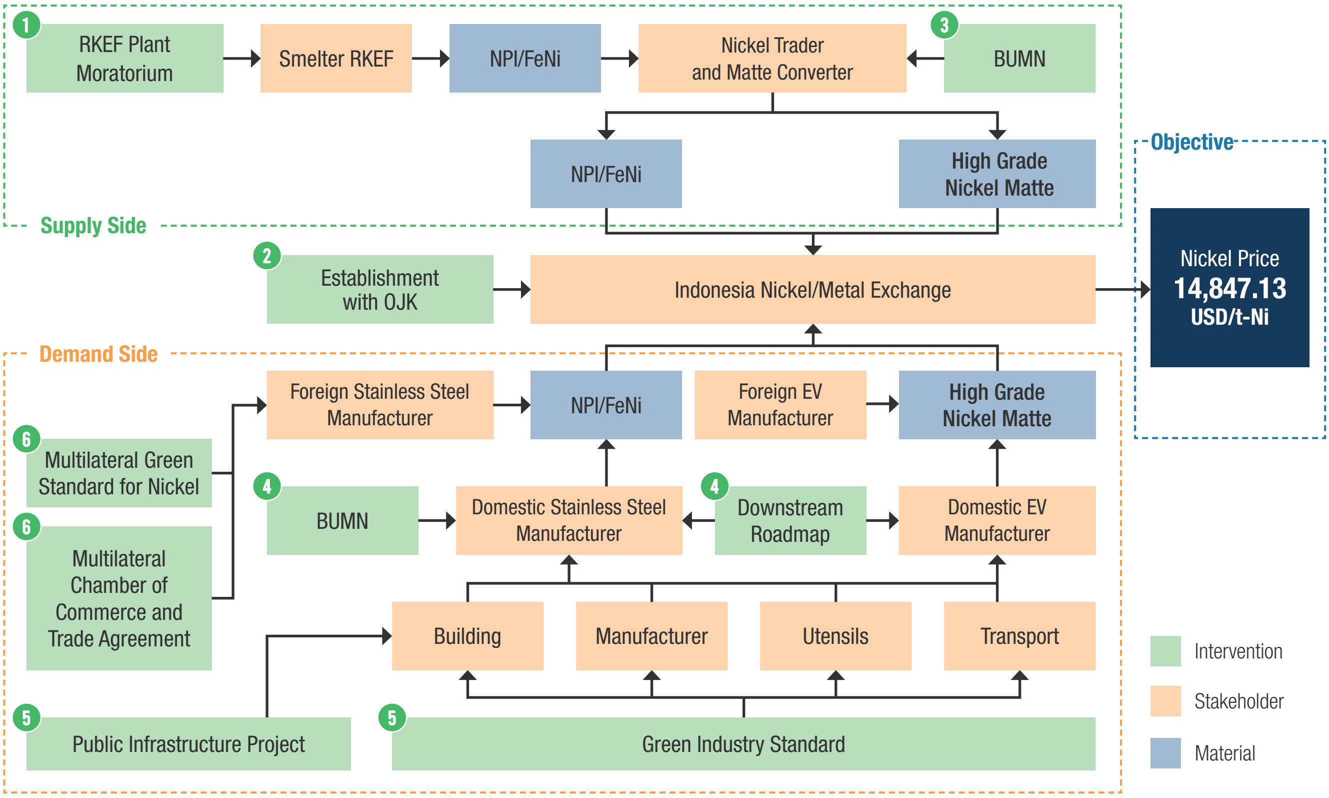


Table 22.
Policy framework to control the price of nickel in the market from 2025-2045

Policy Direction	**Implementation of Nickel Price Control Mechanism**
Objective	**Nickel supply is increasingly controlled and coupled with domestic demand creation, maintaining prices at a level that ensures sufficient margins to support decarbonization**

Challenge	Action Plan	Measure of Success	Milestone					Lead Agency	Other Related Parties
			2025-2029		2030–2034	2035–2039	2040–2045		
Oversupply of pyrometallurgy nickel	Limiting nickel production capacity based on global demand and price conditions	RKEF smelter moratorium policy issued	Review and evaluation of Indonesia's mineral balance	Determination of the legal basis for the RKEF smelter moratorium based on mineral balance	Revision of the legal basis for the RKEF smelter moratorium based on the update of the mineral balance and the nickel downstream roadmap			Ministry of Energy and Mineral Resources, Ministry of Industry	Ministry of Trade, Ministry of Investment
Unstable and low nickel prices make decarbonization projects less financially viable for the industry	Establishment of the Indonesia Nickel/Metal Exchange	The general selling price of nickel is based on domestic nickel supply and demand conditions	Preparation of a study on the planning of the Indonesian nickel exchange/ metal exchange	Determination of the legal basis of the nickel exchange/metal exchange of Indonesia	Implementation of metal/nickel trade monitoring as well as domestic supply and demand conditions			Ministry of Trade	Ministry of Energy and Mineral Resources, Ministry of Industry, OJK, Nickel Industry
		The reference price of green nickel that meets the Indonesian Green Nickel Standard is available	Preparation of a study on the determination of the reference price of green nickel and the implementation of discussions with Indonesia's nickel trading partner countries to achieve a win-win solution		Determination of green nickel reference prices that meet the Indonesian Green Nickel Standard	Periodic evaluation and adjustment of the reference price of green nickel	Periodic evaluation and adjustment of the reference price of green nickel	Ministry of Energy and Mineral Resources, Ministry of Trade, Ministry of Industry	Ministry of SOEs
	Establishment of a dedicated SOE for maintaining nickel balance	The availability of a mechanism to stabilize the price of nickel by dynamically regulating the circulation flow of nickel products	Preparation of a nickel downstream roadmap	Determination of the legal basis that provides the function of regulating the flow of national nickel circulation in the domestic and international markets	Adjustment of the purchase quota of NPI, FeNi, and Low Grade Nickel Matte based on the exchange price, with the purchase price according to the decarbonization roadmap Adjustment of the production capacity of high grade nickel matte based on the price of NPI, FeNi, and Low Grade Nickel Matte, as well as the demand conditions Adjustment of the sales quota of NPI, FeNi, and Low Grade Nickel Matte based on the exchange price.			Ministry of SOEs	Nickel Bureau/ SOEs Nickel Management, Ministry of Investment, Indonesia Nickel/Metal Exchange, Danantara, Ministry of Industry, nickel industry

Challenge	Action Plan	Measure of Success	Milestone					Lead Agency	Other Related Parties
			2025-2029		2030–2034	2035–2039	2040–2045		
Fluctuating global demand and limited domestic demand for pyrometallurgical nickel products (FeNi and NPI).	Development of domestic downstream industries to maintain stable demand for RKEF products	The increasing number of downstream industries that produce high grade nickel matte	Preparation of a nickel downstream roadmap	Determination of legal basis and status as PSN for stainless steel and/or high grade nickel matte producing industries Preparation of business model studies and feasibility studies of these industries Preparation of studies on the provision of fiscal & non-fiscal incentives for these industries	Implementation of public infrastructure development programs to support the implementation of PSN Determination of annual SOE production targets based on the conditions of nickel supply and demand balance as well as the need for stainless steel and high grade nickel matte in the end user industry			Ministry of National Development Planning/ Bappenas	Ministry of SOEs, Ministry of Energy and Mineral Resources, Ministry of Investment, Ministry of Industry, and Antara
		The increasing number of downstream industries that produce stainless steel							
	Setting emission standards/ thresholds for final products that use nickel (e.g. buildings, vehicles, household appliances)	The issuance and/or increasing adoption of emission standards/ thresholds for a variety of end products that utilize nickel (e.g. buildings, vehicles, household appliances)	Issuance of national standards and/or recognition of voluntary standards that regulate emission thresholds for a variety of end products that utilize nickel (e.g. buildings, vehicles, and household appliances)	Issuance of regulations to require the implementation of standards containing emission thresholds in the industry producing various final products	Implementation of certification and periodic assistance to the industry producing various final products			Ministry of Industry	Ministry of PUPR, BSN, third party verifier, voluntary standard setter (e.g. GBCI), industry producer of various final products

■ Challenge

■ Action Plan

■ Policy on technology and infrastructure

■ Policy on standard and regulation

■ Policy on financing and investment

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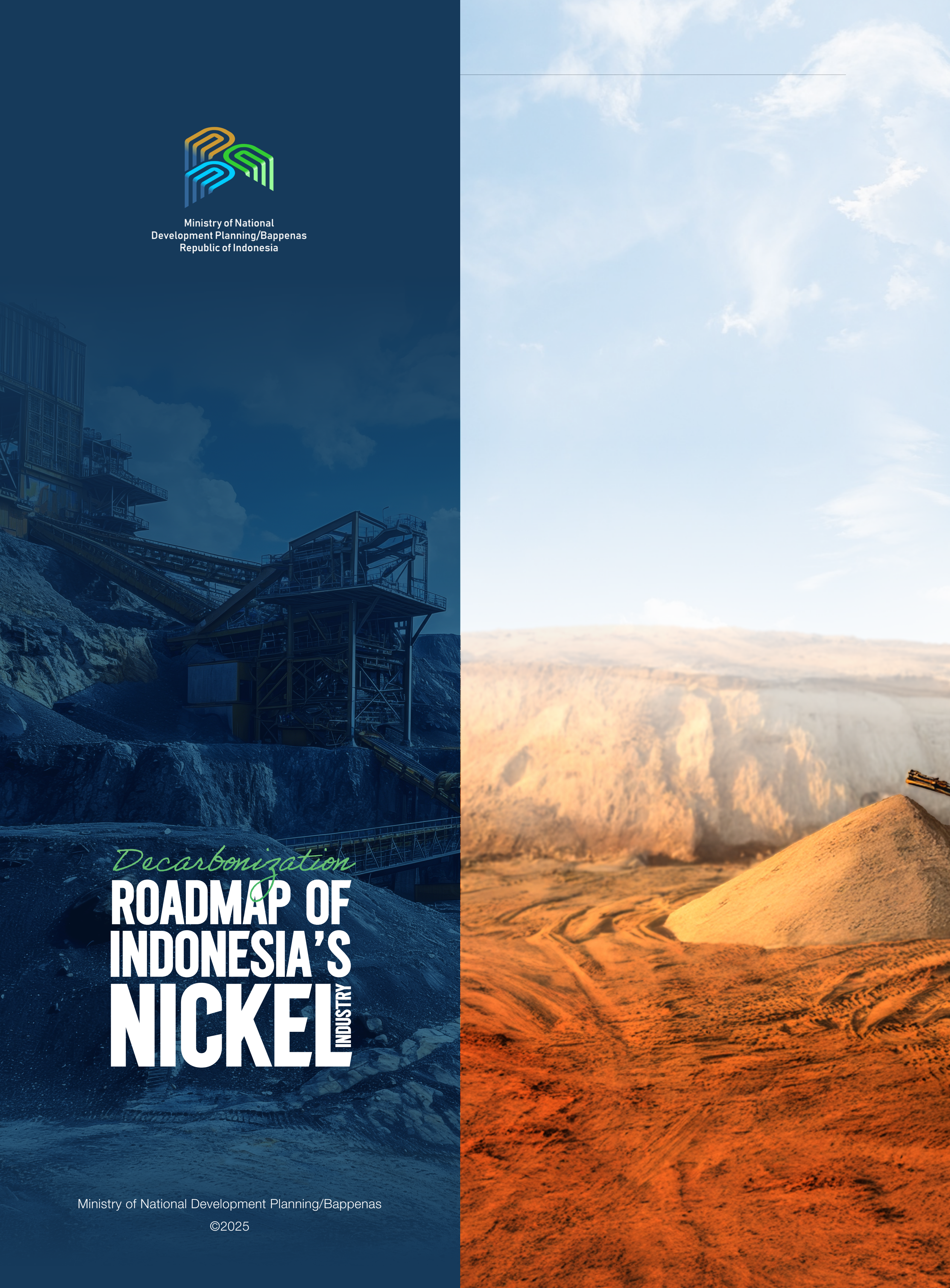

Decarbonization ROADMAP OF INDONESIA'S NICKEL INDUSTRY

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