Advancing Clean Metals

Decarbonizing captive power in Indonesia's nickel and aluminum industries

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About RMI

Rocky Mountain Institute (RMI) is an independent, nonpartisan nonprofit founded in 1982 that transforms global energy systems through market-driven solutions to secure a prosperous, resilient, clean energy future for all. In collaboration with businesses, policymakers, funders, communities, and other partners, RMI drives investment to scale clean energy solutions, reduce energy waste, and boost access to affordable clean energy in ways that enhance security, strengthen the economy, and improve people's livelihoods. RMI is active in over 60 countries.

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Executive Summary

Indonesia's rapid expansion of nickel and aluminum processing is the centerpiece of the country's critical minerals "downstreaming" strategy. This strategy plays a central role in Indonesia's broader development agenda, aiming to increase the added value of domestic resources by promoting in-country processing and refining. In this context, nickel and aluminum have experienced significant growth over the past decade, making these critical minerals a flagship for the country. However, this expansion is being powered by a surge in off-grid coal-fired power plants, which now poses a significant threat to Indonesia's climate goals and its competitiveness in low-carbon markets.

Based on an RMI-developed database, which compiles captive power capacity data from government and public sources, Indonesia's captive power capacity has more than doubled, rising from 9.6 gigawatts (GW) in 2019 to 22.9 GW in 2024. Over 81% of this capacity, or approximately 18.6 GW, is coal fired and operates entirely outside of oversight by PLN, Indonesia's state-owned national utility. Most of the growth is concentrated in the nickel sector — particularly from energy-intensive rotary kiln-electric furnace (RKEF) smelters, a type of pyrometallurgical processing technology, which accounts for 61%, or nearly 14 GW, of captive capacity. Aluminum processing, while smaller in scale, adds about 1 GW, with a greater share coming from hydropower.

This trajectory is expected to continue. If current projects proceed as planned, the nickel and aluminum industries are poised for substantial growth in captive power demand by 2030. The nickel sector alone is projected to add 6.5 GW of new capacity, of which 90%, or 5.8 GW, will be coal fired. Meanwhile, the aluminum sector is expected to contribute the second-largest increase, with around 3.8 GW in additional captive power and 63%, or 2.4 GW, of that coming from coal.

As a result, coal-fired captive power is now emerging as the primary driver of new coal capacity in Indonesia. According to PLN's electricity supply business plan RUPTL 2025–2034, although no new on-grid coal power plants are scheduled for development, approximately 8.5 GW of new captive coal power plant capacity is anticipated by 2030, outpacing on-grid additions. This expansion risks locking in decades of high emissions and directly undermines Indonesia's pledge to peak power sector emissions and achieve net zero by 2060.

The climate impact is already tangible. In 2023, nickel-related activities alone emitted 170.2 million tons of CO_2 ($MtCO_2$) equivalent to 22% of Indonesia's emissions from the energy sector and industrial processes and product use — with power accounting for the majority (60%) of the industry's emissions. A planned 500 kiloton (kt)/year aluminum smelter powered by 1.1 GW of captive coal that will be completed in 2025 is projected to emit 5.2 $MtCO_2$ annually, nearly 2% of the national power sector's total.

Although the government has pledged to reduce emissions from captive coal under Presidential Regulation No. 112/2022, exemptions for industrial estates and national strategic projects continue to enable coal expansion. This regulatory gap, combined with limited grid access, weak market signals, and lack of verified emissions data, is entrenching coal in Indonesia's most strategically important export sectors for decades to come.

The strategic imperatives of decarbonizing the power supply in the nickel and aluminum industries

The global shift toward low-carbon supply chains is creating a challenge and an opportunity for Indonesia's critical minerals sector. Trade instruments like the EU's Carbon Border Adjustment Mechanism (CBAM) and Battery Passport as well as buyer coalitions such as the First Movers Coalition are setting new baselines for verifiable low-emissions materials. Domestically, Indonesia's planned Emissions Trading System (ETS) with a cap-and-trade approach is planned to roll out in 2025 for captive power, further raising the stakes for coal-reliant producers.

At the same time, declining international nickel prices are putting financial pressure on the producers, many of whom already operate on narrow margins. Transitioning fully to renewables remains challenging, especially in regions with limited renewable potential. Although PLN has outlined plans to extend grid access to key industrial hubs in its RUPTL 2025–2034, significant technical and financial challenges remain. Transmission development requires high up-front capital investment and long-term demand certainty to justify project viability, especially in remote or underdeveloped areas.

In this context, hybrid power systems that integrate a mix of renewables with existing fossil assets may offer pragmatic near-term pathways to reduced emissions and cost control. However, these must be seen as transitional. To ensure long-term sustainability and climate alignment, a forward-looking framework — one that reduces fossil energy, scales clean power, and responds to the evolving demands of carbon-constrained global trade — could be considered as part of the country's industrial strategy.

Decarbonizing Indonesia's Power Sector for Nickel and Aluminum Is a Must

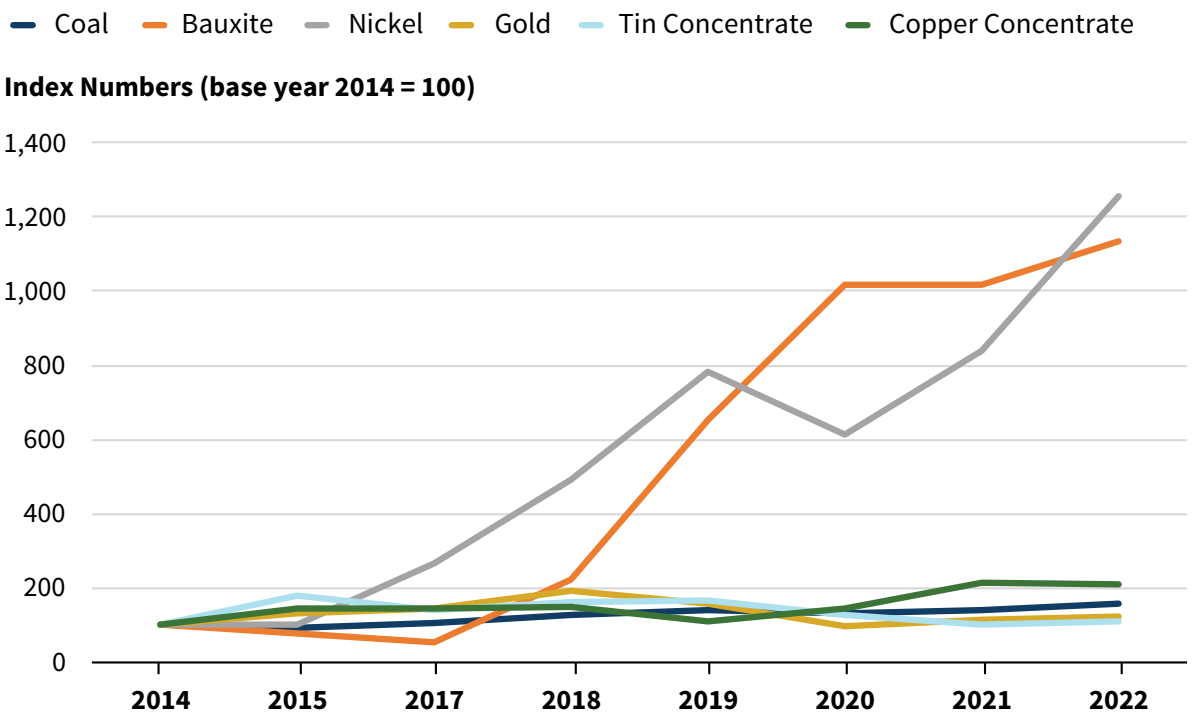
Processing of nickel and aluminum is rapidly expanding

Nickel and aluminum are among the fastest-growing industrial sectors in Indonesia, driven by the government's downstreaming strategy. With the rising global demand for electric vehicles, batteries, and clean energy technologies, these minerals have become central to Indonesia's industrial policy. The downstreaming strategy aims to capture greater economic value from domestic resources by fostering a local processing industry, reducing reliance on raw material exports.

Over the past decade, Indonesia has strategically positioned its abundant critical minerals, particularly nickel and bauxite, at the core of this transformation (see Exhibit 1). The government's export bans on nickel ore in 2020 and bauxite in 2023 have catalyzed a rapid expansion of domestic smelting and refining capacity, especially in mineral-rich regions such as Sulawesi, Kalimantan, and Maluku.

Exhibit 1

Indexed growth of Indonesia's minerals production, 2014-22



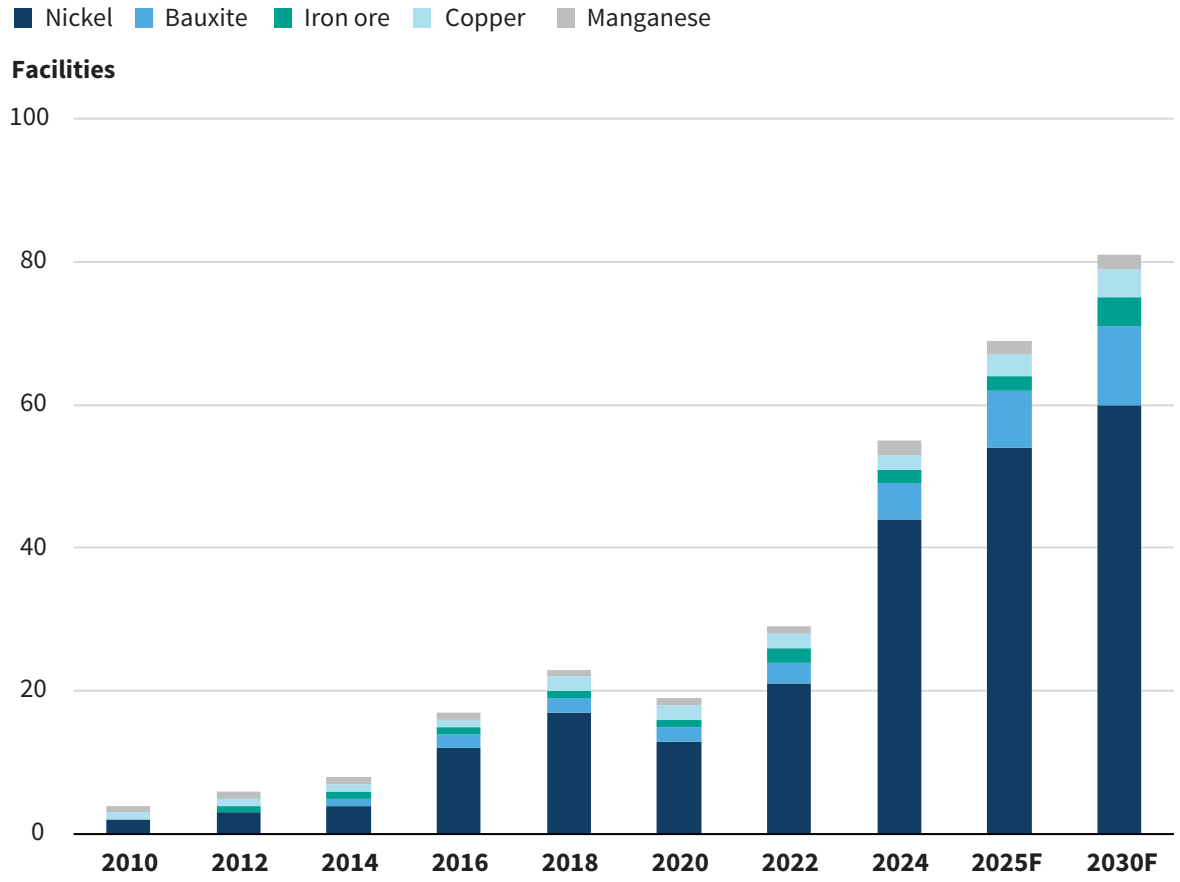
Note: This chart presents indexed mineral production value, using 2014 as the base year (index = 100). The value is a normalization to compare the growth trends across different minerals, regardless of their original units or production volumes. Data from 2016 not available.

RMI Graphic. Source: Indonesia Bureau of Statistics

Nickel has emerged as Indonesia's primary mineral. Production has rapidly scaled, contributing over 50% of global output in 2023,[1] and firmly establishing the country as a dominant player in the market. Globally, nickel demand remained steady between 2018 and 2020 at around 2.4 million tons (Mt) but then experienced significant growth to 3.1 Mt in 2023.[2] Historically, nickel demand was primarily driven by alloys, which accounted for 75% of the total nickel demand in 2015. However, from 2020 to 2023, demand shifted substantially toward the clean energy sector, which became the main factor behind a 30% increase in overall demand during this period. The International Energy Agency projected that demand is set to rise further to 4.5 Mt by 2030 under a business-as-usual scenario and to 5.6 Mt by 2030 under a net-zero scenario.

Bauxite has also been experiencing rapid development, with more smelters being built across the country to support alumina refining and aluminum production. In 2023, four alumina refineries were operating in Indonesia able to process 12.25 Mt of bauxite and yielding over 4.3 Mt of alumina annually.[3] In the same year, the country's annual aluminum production was around 250 kt, while domestic demand was about 1 Mt.[4] This development of alumina and aluminum processing in Indonesia is part of a strategic move by the government to fulfill domestic demand and reduce reliance on imports.

Exhibit 2 Growth of smelter facilities in Indonesia by mineral, 2010–30



Note: The data reflects the number of smelter facilities (not individual processing units/lines) that are operational, under construction, or permitted. Forecasts for 2025 and 2030 are based on pipeline projects and government targets.

RMI Graphic. Sources: Ministry of Energy and Mineral Resources (MEMR), Petromindo, Ministry of Industry

As indicated in Exhibit 2, by 2030, if current projects proceed as planned, Indonesia is expected to have approximately 60 nickel smelting facilities,[5] representing more than a tenfold increase from 2014. Most of these new developments are concentrated in Sulawesi and Maluku. The aluminum sector is expanding at a more measured pace. The number of aluminum smelting or alumina refining facilities is expected to reach at least 11 facilities by 2030, comprising seven alumina refineries and four aluminum smelters, with new projects primarily located in Kalimantan and Sumatra.

Rapid nickel and aluminum expansion is driving energy emissions

The expansion of smelters has led to a surge in industrial emissions, particularly from captive power plants that supply electricity to the processing facilities. In 2023 alone, nickel-related activities from mining to processing were responsible for an estimated 170.2 $MtCO_2$,[6] equal to approximately 22% of Indonesia's emissions from the energy sector and industrial processes and product use. Of this total, around 60% is attributed to electricity consumption, primarily from captive power to meet the high, continuous energy demands of smelting operations.

For bauxite-related processing, covering both alumina refining and aluminum smelting, the total national emissions amount was not yet fully quantified as of this report's publication. However, a study indicates that one planned aluminum smelter that will be completed in 2025 in Kalimantan, with an annual production capacity of 500 kt and powered by a 1.1 gigawatt (GW) captive coal-fired power plant, is projected to emit approximately 5.2 $MtCO_2$ per year. The emissions would be equivalent to nearly 2% of Indonesia's total power sector emissions in 2022, which stood at 296 $MtCO_2$.[7]

The significance of captive power in supporting smelter operations cannot be overstated. By 2024, it was estimated that Indonesia's captive power capacity was about 22.9 GW, more than double the 9.6 GW in 2019. This significant growth has been driven primarily by the rapid expansion of nickel processing, which currently accounts for approximately 61%, or 14 GW, of captive capacity. With completion of the nickel facilities still under construction, the figure is expected to grow significantly in the coming years. The aluminum industry, though expanding at a more measured pace, currently utilizes around 1 GW. However, with several alumina refineries and aluminum smelters in development, the sector's captive power demand is also projected to rise. Notably, around 81%, or 18.6 GW, of total captive power is still generated by coal-fired power plants, underscoring the industrial sector's continued dependence on coal to meet its energy demands.

The growing reliance on captive power, and coal-fired power in particular, illustrates a deeper structural challenge within Indonesia's energy and industrial systems. As industry grows, especially from downstreaming minerals, so too does the demand for dedicated captive power infrastructure. The 2025 National Electricity Master Plan (RUKN) estimates that by 2060, the industrial sector will contribute to 43% of total electricity demand, the highest share among all sectors. Smelters, particularly for critical minerals, are identified as a major driver of industrial electricity demand, with many still expected to rely on coal-fired power.

The decarbonization imperative for nickel and aluminum energy supply

The significant growth of nickel and aluminum smelting industries in Indonesia, accompanied by their heavy reliance on coal-fired captive power, underscores an urgent need for transitioning to sustainable energy sources. As smelter operations continue to expand rapidly, driven by the country's strategic downstream processing initiatives, their considerable and continuous energy demands further entrench

dependency on coal-fired power, presenting substantial challenges to emissions reduction and environmental sustainability.

With evolving landscapes of global trade and investment, markets are becoming increasingly carbon conscious. Mechanisms such as the EU's Carbon Border Adjustment Mechanism (CBAM) and Battery Passport, along with emerging domestic policies like Indonesia's Emissions Trading System (ETS), are redefining competitiveness around the carbon footprint of industrial products. In this context, decarbonizing the power supply for energy-intensive industries is not only essential for meeting Indonesia's domestic climate goals, but also critical for securing future market access and safeguarding the long-term competitiveness of Indonesia's nickel and aluminum products.

This report focuses on nickel and aluminum because these two metals are poised to experience significant growth in production capacity and energy demand over the coming years. Additionally, nickel smelting facilities are under construction or in the pipeline, reinforcing nickel's role at the center of Indonesia's downstream industrial expansion. Similarly, aluminum is gaining strategic importance, with several alumina refineries and aluminum smelters planned or underway. These facilities are not only capital-intensive but also extremely energy intensive. As a result, the growth of these two sectors will significantly drive industrial energy demand and associated emissions, especially in the construction of captive power plants.

While decarbonizing the power supply is a critical step, understanding that industrial emissions are not driven by electricity alone is also critical. It is essential to understand where emissions occur across the entire value chain, from mining to refining to smelting and downstream processing. Without this clarity, focusing solely on power solutions risks overlooking other high-impact emissions sources, such as thermal energy use, process-related CO_2, and material inputs.

Emissions in Nickel and Aluminum Processing: Sources, Technologies, and Reduction

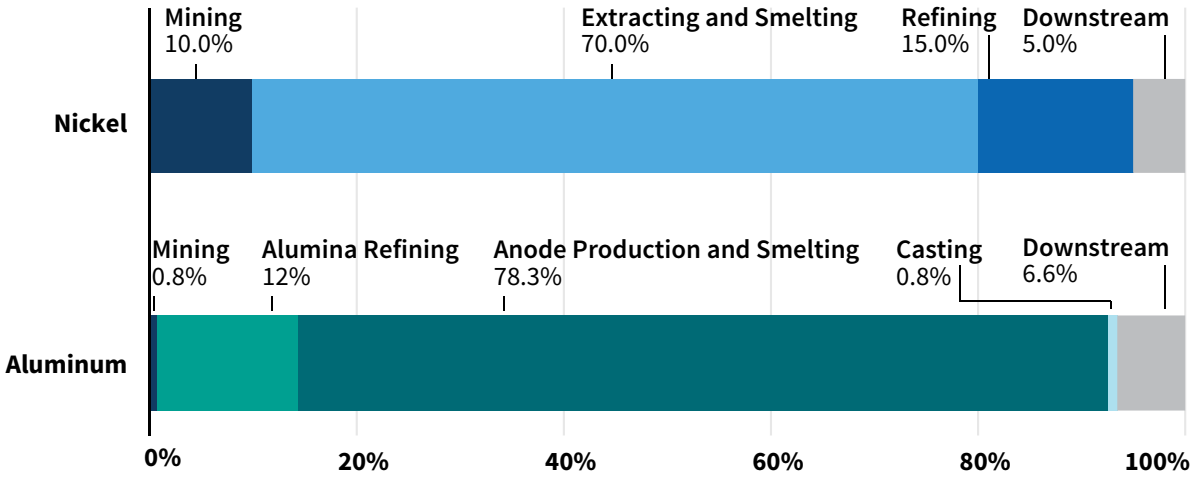
Understanding the emissions distribution across nickel and aluminum value chains

The rapid growth of Indonesia's nickel and aluminum sectors detailed earlier necessitates a closer examination of emissions sources and their mitigation potential. Understanding these emissions is critical for shaping effective decarbonization strategies.

Exhibit 3 shows the emissions distribution across the value chains for nickel and aluminum from mining to downstream uses. The extraction and processing stages are the primary contributors to emissions for both value chains. The emissions profiles for these minerals differ based on various stages and technological pathways. In both sectors, sources of emissions include electricity consumption, thermal energy, process-related CO_2 emissions, and the use of ancillary materials.

Exhibit 3

Emissions distribution across nickel and aluminum value chains



Note: Emissions include combustion from both stationary and non-stationary sources, as well as processing materials such as reductants, electricity, heat sources, and waste and fugitive emissions.

RMI Graphic. Sources: International Aluminum Institute, https://3stepsolutions.s3-accelerate.amazonaws.com/assets/custom/010856/downloads/Making-1.5-Aligned-Aluminium-possible.pdf; and International Finance Corporation, https://documents.worldbank.org//en/publication/documents-reports/documentdetail/099422010202312964

In the nickel processing sector, two main technological pathways have emerged: the rotary kiln-electric furnace (RKEF), a form of pyrometallurgy, and high-pressure acid leaching (HPAL), a hydrometallurgical process. These two methods differ significantly in process characteristics, emissions intensities, and end products.

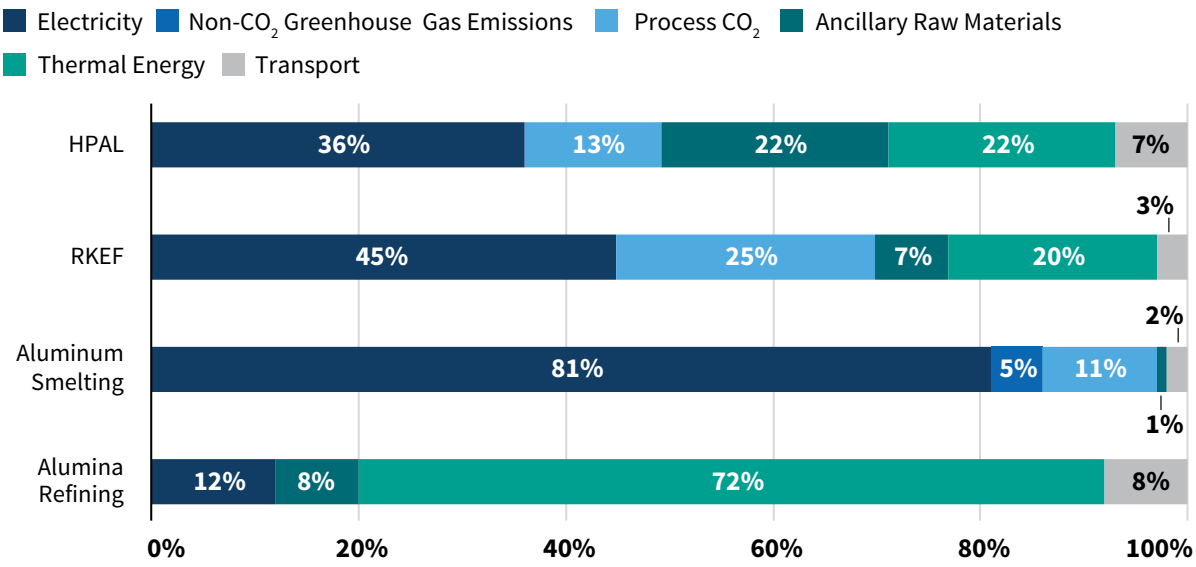
RKEFs are primarily used to produce ferronickel (FeNi) or nickel pig iron (NPI), materials mainly destined for the stainless-steel industry. However, RKEF-derived products can also be further refined into nickel matte, which can then be processed into nickel sulphate — a key precursor for battery production. By contrast, HPAL directly targets the production of mixed hydroxide precipitate (MHP), an intermediate product rich in nickel and cobalt. MHP can subsequently be refined into nickel sulphate as well, making HPAL a critical technology for supporting the electric vehicle and energy storage sectors.

The aluminum value chain begins with the extraction of bauxite ore, which is refined into alumina and smelted to produce primary aluminum. Similar to nickel, Indonesia has been expanding its downstream capacity in aluminum production, aiming to strengthen its position in supplying critical materials for energy transition technologies and infrastructure development.

Exhibit 4 illustrates the breakdown of emissions sources within the nickel and aluminum processing value chains, showing the distinct emissions profiles associated with each production technology and stage. Notably the emissions sources vary substantially between processes.

Exhibit 4

Emissions breakdown by source in nickel and aluminum processing, extraction, or smelting



Note: RKEF is for NPI/FeNi products. Values are global average. Electricity includes emissions from power consumed during electrolysis (aluminum), RKEF, pumps, and other electronic systems. Thermal energy refers to the combustion of fossil fuel for heat and steam. Process CO_2 includes emissions from chemical reactions such as anode oxidation, reductants, and neutralization agents. Non-CO_2 gases represent gases with global warming potential such as perfluorocarbons. Ancillary raw materials include upstream emissions, such as caustic soda, lime, sulfuric acid, and carbon anodes. Transport covers the emissions from transporting raw materials.

RMI Graphic. Sources: International Aluminum Institute, https://3stepsolutions.s3-accelerate.amazonaws.com/assets/custom/010856/downloads/Making-1.5-Aligned-Aluminium-possible.pdf; and Nickel Institute Life Cycle Data, https://nickelinstitute.org/media/r5wn5u4j/2025-lifecycledata-executive-summary.pdf

In nickel processing, RKEF emissions are driven largely by electricity consumption (45%) and significant process-related CO_2 emissions (25%), as well as thermal energy (20%). Similarly, in the HPAL process, electricity (36%) and thermal energy (22%) are major contributors. However, HPAL also produces substantial non-CO_2 greenhouse gas (GHG) emissions (13%) and notable process-related CO_2 emissions (22%), illustrating that decarbonization must address multiple emissions streams beyond electricity alone.

In aluminum processing, the smelting stage stands out for its very high reliance on electricity, constituting about 81% of total emissions due to the electrolytic reduction process. Yet process-related CO_2 emissions (11%) also represent an important additional emissions source. Conversely, alumina refining emissions are dominated by thermal energy (72%), reflecting the high-temperature requirements of refining bauxite.

Although this document delves deep into electricity, the breakdown clearly indicates that electricity decarbonization alone will not suffice to fully decarbonize the entire value chain. Effective strategies for nickel and aluminum processing across stages in their value chains must also address such other critical emissions sources as thermal energy use, process-related CO_2 emissions, and non-CO_2 GHG emissions, necessitating a comprehensive approach to emissions management.

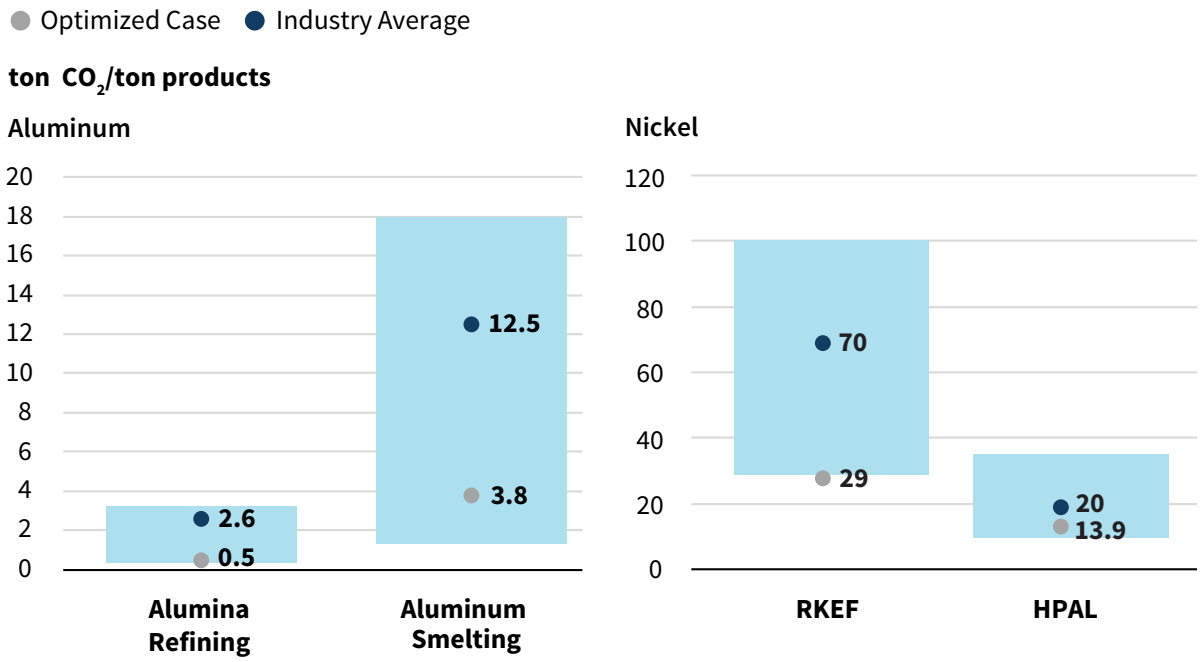
Emissions intensity comparison across nickel and aluminum processing technologies

A closer look at emissions intensity across processing technologies is further illustrated in Exhibit 5. Among the processing technologies, RKEF operations emerge as one of the most carbon-intensive processes. RKEF operations in Indonesia typically emit 70–100 tons of CO_2 per ton of product (tCO_2/t), primarily due to their reliance on captive coal power plant and coal reductants. However, nickel processing at a Sulawesi-based company shows that carbon emissions can be significantly optimized to about 29 tCO_2/t, especially when hydropower is used as the main source of electricity.

In contrast, HPAL global averages are closer to 20 tCO_2/t with companies that utilize waste heat recovery and operational efficiency able to reach as low as 7–13.9 tCO_2/t. That said, HPAL presents other environmental challenges because it generates large volumes of acidic tailings — around 1.4–1.6 tons of waste per nickel ton[8] — which pose significant environmental risks, especially when not properly neutralized or stored.

Exhibit 5

Emissions intensity ranges for nickel and aluminum processing technologies



Note: Emissions intensities shown are Scope 1 (direct emissions) and 2 (indirect emissions), in ton CO_2 per ton of product. Bars reflect the global ranges; diamonds indicate the industry averages; circles represent optimized cases where operations are highly efficient and renewable energy is used significantly.

RMI Graphic. Sources: International Aluminum Institute, https://3stepsolutions.s3-accelerate.amazonaws.com/assets/custom/010856/downloads/Making-1.5-Aligned-Aluminium-possible.pdf; Nickel Institute Life Cycle Data, https://nickelinstitute.org/media/r5wn5u4j/2025-lifecycledata-executive-summary.pdf; Institute for Energy Economics and Financial Analysis (IEEFA), https://ieefa.org/resources/indonesias-nickel-companies-need-renewable-energy-amid-increasing-production; and multiple companies' sustainability reports

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In the aluminum value chain, smelting is also highly carbon-intensive, with an average emissions intensity of 12.5 tCO_2/t of aluminum, primarily due to the energy required for electrolysis. However, facilities powered by renewable electricity, such as a company based in Kalimantan utilizing hydropower, can reduce emissions to as low as 3.8 tCO_2/t. Alumina refining, though less carbon-intensive than smelting, still exhibits a wide range, from 0.5 to 3.0 tCO_2/t of alumina, depending on the energy source and technology efficiency.

Global experience suggests that significant decarbonization is achievable with targeted technology choices and market incentives. Aluminum and nickel producers in China and Australia are increasingly turning to renewable energy to achieve emissions reductions. In China, aluminum producers are strategically relocating production capacities to provinces rich in hydropower, such as Yunnan, significantly reducing reliance on coal-fired captive power. An Australia-based company has secured a long-term, low-carbon nickel supply agreement with US automotive manufacturers, highlighting how market incentives can drive industrial decarbonization. Responding to this demand, the company has entered renewable energy power purchase agreements (PPAs) that enable 100% clean energy to power its nickel operation in Western Australia. These examples demonstrate that emissions-intensive processes can substantially cut their carbon footprints when provided with appropriate infrastructure and market incentives.

Power Behind Processing: Captive Power Growth in Nickel and Aluminum Sectors

Nickel and aluminum smelters, in particular, require a large, continuous, and reliable power supply, often in locations far from the existing grid infrastructure. In the absence of limited energy access, most companies resort to building their own captive power plants. This trend is expected to accelerate, in line with Indonesia's downstreaming strategy, as companies rush to develop energy infrastructure needed for their operations.

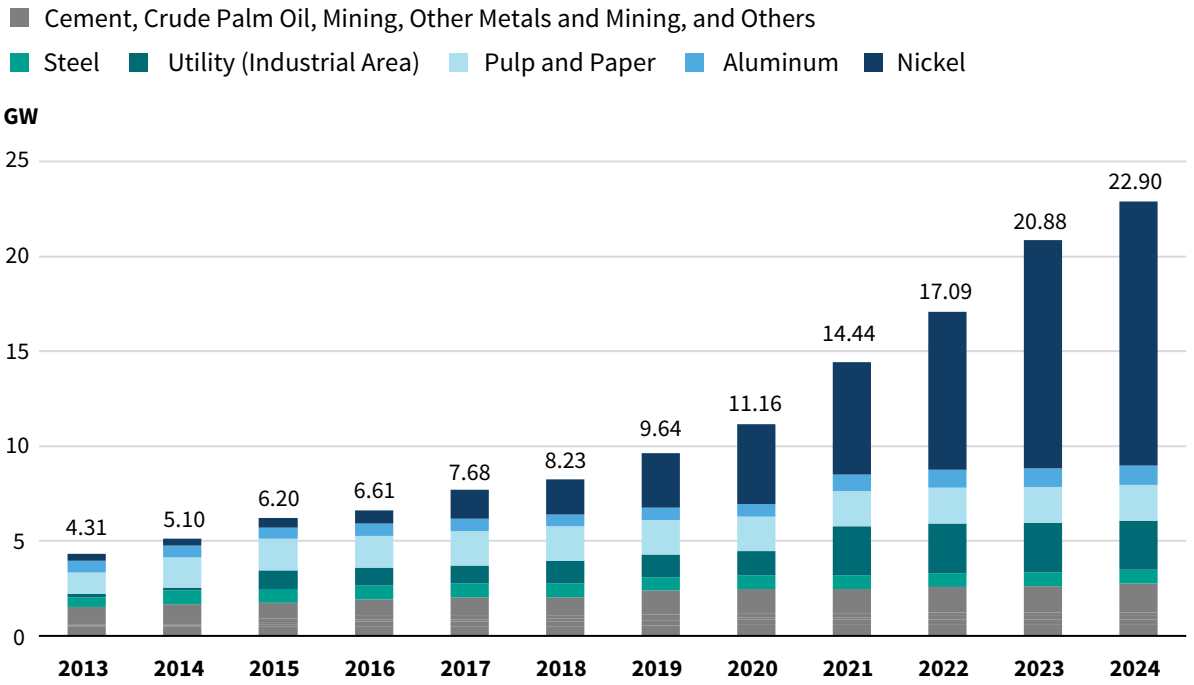
Captive power capacity, especially coal, has increased significantly in the past decade, driven by the nickel industry

RMI compiled captive power capacity data from publicly available sources and government focus group discussions, as displayed in Exhibit 6. Although official government data provides aggregated information, it does not publicly disclose asset-level details. In contrast, publicly available datasets offer granularity by capturing breakdowns by plant, type, capacity, and associated industries. Between 2019 and 2024, captive power capacity expanded by approximately 13.3 GW, more than doubling from 2019 levels. This brought the capacity to 22.9 GW in 2024, compared with 9.6 GW in 2019. Growth was primarily driven by the electricity needs associated with critical raw materials (CRM), particularly nickel processing via RKEFs.

As of 2024, coal-fired power plants accounted for the largest share of captive capacity, over 80%, or approximately 18.6 GW, operating entirely outside the jurisdiction of Indonesia's state-owned utility, PLN. They are also responsible for the highest number of new deployments over the past five years. Gas fired power plants follow, contributing 2 GW to the total capacity in 2024. By contrast, captive renewable energy remains marginal, supplying less than 5% of captive power, or around 1 GW. The majority of this comes from hydropower, and smaller contributions come from bioenergy and recent additions of solar photovoltaic (PV).

If the 18.6 GW estimate for captive coal-fired power plants holds, it would represent more than 30% of Indonesia's total national coal fleet, underscoring the significant and often overlooked role of captive coal in the country's energy and emissions landscape.

Exhibit 6 Captive power plant capacity by industrial sector, 2013-24

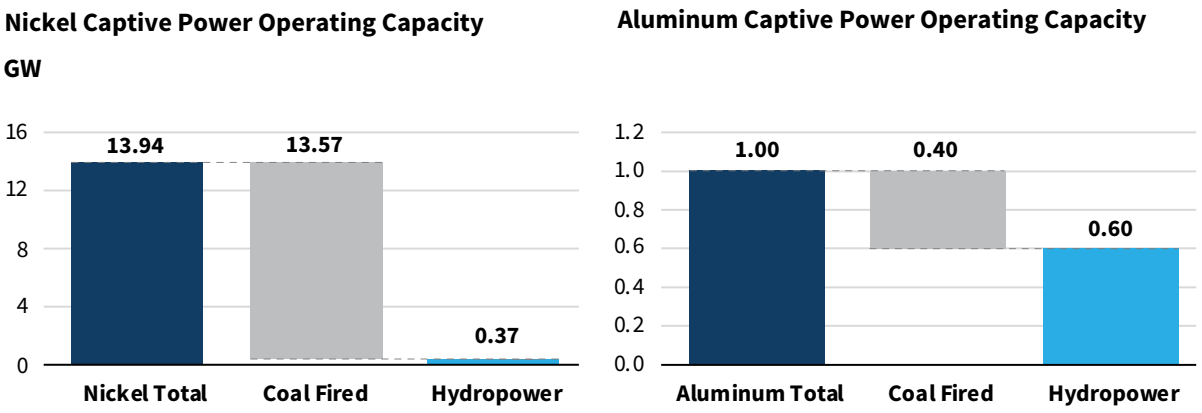


Note: The grey area in the graph is shaded to indicate its classification as a distinct category. "Other Metals and Mining" includes gold, copper, etc. "Others" includes sugar, chemicals, fertilizer, petroleum and refining, textiles, utilities, and agriculture industries.

RMI Graphic. Sources: Publicly available information from Global Energy Monitor (2025), RUKN (2025), and stakeholder focus group discussions

The nickel industry accounts for the largest share of captive power capacity, with a total of 13.94 GW operating in 2024. As illustrated in Exhibit 7, almost the entire capacity, 13.57 GW is coal fired, with only 0.37 GW sourced from hydropower. This heavy reliance on coal highlights the sector's dependence on the high-emissions power system, especially in RKEF facilities where uninterrupted electricity is critical.

Exhibit 7 Nickel and aluminum total operating capacity of captive power as of 2024



RMI Graphic. Sources: Publicly available information from Global Energy Monitor (2025), RUKN (2025), and stakeholders focus group discussions

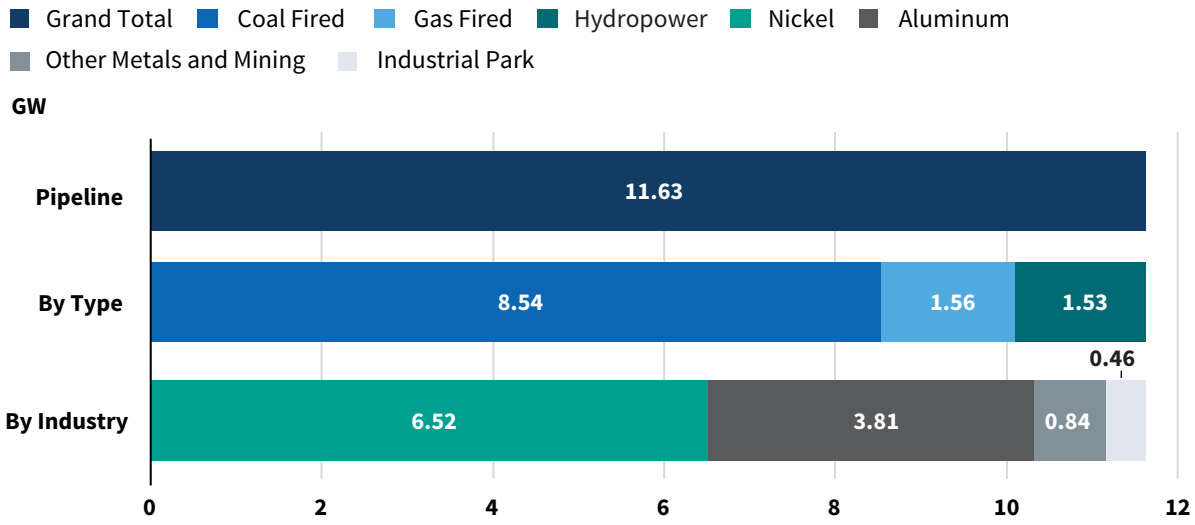
In contrast, the aluminum industry operates with a comparatively smaller captive capacity, totaling around 1 GW. The energy mix for the aluminum sector is also more balanced, with 0.4 GW coming from coal, and hydropower contributing a larger share of 0.6 GW. The stronger uptake in hydropower in aluminum production is driven largely by the presence of integrated hydropower assets in regions such as North Kalimantan.

Captive power outlook for supplying energy to nickel and aluminum processing facilities by 2030

Given the number of processing facilities under construction or in planning, the captive power capacity for both sectors is projected to increase. By 2030, nickel processing will continue to dominate as a captive power user, as more smelters are being constructed, mostly in Sulawesi and Maluku. Aluminum, by contrast, is poised to become the second-biggest user of captive power, as new alumina refining and aluminum facilities are under construction in regions including Kalimantan and Riau.

Exhibit 8

Captive power plant pipeline to 2030 by plant type and associated industries



Note: "Pipeline" refers to projects that are under construction, in planning, permitted, or awaiting permits. "Other Metals and Mining" includes gold, copper, and similar extractive industries. "Others" encompasses industrial parks and oil refineries.

RMI Graphic. Sources: Publicly available information from Global Energy Monitor (2025), Sunrise Project (2024), and RUKN (2025)

As illustrated in Exhibit 8, between 2024 and 2030, the nickel industry will add 6.5 GW of new captive power capacity. That will increase total capacity to 20 GW in 2030 with 5.8 GW coal fired, 0.5 GW hydropower, and 0.15 GW gas fired. Moreover, the aluminum sector will see the second-largest captive power expansion, growing from 1 GW in 2024 to a total capacity of 4.8 GW by 2030. The new additions will come from 2.4 GW of coal-fired power and 1.4 GW of hydropower. As both sectors expand, the pressure to secure reliable and clean power will intensify, making the choice of energy sources a central issue for aligning the country's industrial growth with climate goals.

Weighing the Trade-offs: Captive Coal Default, Renewable Energy, Grid Connections, and Their Constraints

The dominance of coal as captive power in Indonesia arises from the leniency of the country's current policy. Coal-fired captive power offers dispatchable power at scale, requires relatively modest infrastructure investments, and benefits from access to an abundant domestic coal supply. Moreover, the absence of stringent emissions regulations and the nonbinding carbon price mechanisms have done little to discourage the continued use of coal. In effect, the cost advantage of coal remains largely unchallenged, allowing high-emissions power generation to increase unchecked, especially in critical minerals sectors. This reliance comes with significant long-term trade-offs and can undermine the country's climate aspirations. Operating outside PLN's oversight, captive coal plants are excluded from national electricity planning and often have limited regulatory surveillance. As a result, they risk locking in high emissions for decades, making it difficult for the country to align with its climate objectives.

Yet while coal remains the prevailing choice, growing attention is being directed toward lower-emissions alternatives, such as gas and renewable energy. Gas for example, at face value, appears to be a cleaner substitute due to its lower combustion emissions compared to coal. However, it poses a major climate risk due to methane leakage across its supply chain. Methane is a highly potent greenhouse gas, more than 80 times more powerful than CO_2 over a 20-year period. RMI research shows that even a leakage rate as low as 0.2% can erase the climate advantage of natural gas over coal, making the fuel equally harmful.[9] Renewables, although they offer clear environmental benefits, face significant barriers that limit their deployment for large-scale industrial use. They include constraints on infrastructure, lack of regulatory incentives, and around-the-clock operational reliability. For companies, this has created a narrow playing field, with limited flexibility to balance emissions, cost, and power certainty.

The constraints of gas and renewable energy

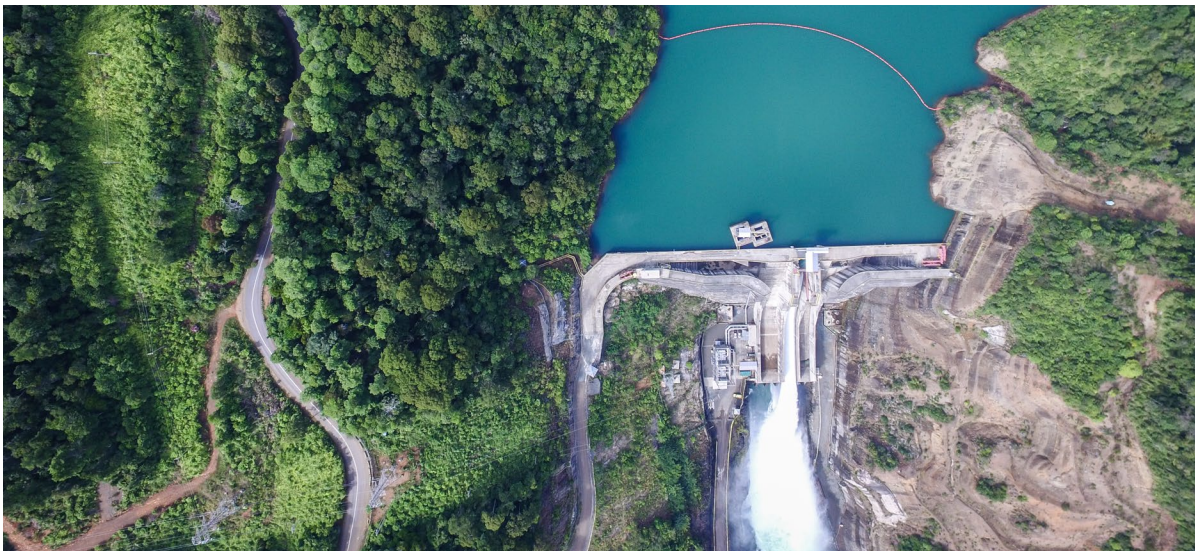
Gas power plants are limited due to the constrained supply of gas and supporting infrastructure, such as liquified natural gas pipelines. Several major mineral smelter projects have managed to secure their gas supply thanks to their inclusion as National Strategic Projects (PSN). However, other producers in regions lacking gas infrastructure face difficulties in obtaining a secure supply. Moreover, the domestic gas market is currently being prioritized for the power sector and several sectors listed in the government's Domestic Market Obligation. Through this regulation, the government capped gas prices at US$6/million British thermal units (MMBtu) and specifically named priority sectors that can leverage this price point, such as fertilizer, petrochemicals, steel, and rubber gloves.[10]

As a result of the exclusion of mining smelters, gas producers had little mandate to supply the smelters. The 2022 plea from Mining Industry Indonesia (MIND ID), the Indonesian state-owned holding company for mining, for special gas pricing for smelters highlights that without a policy directive, smelters were not assured of gas at affordable rates.[11] The government has gradually expanded the list of industries eligible for the Domestic Market Obligation's price to improve competitiveness. Still, even if a non-PSN project

qualifies on paper, securing that gas involves dealing with bureaucracy and coordinating with government enterprises and organizations, which can be hurdles. In cases where domestic gas is fully spoken for, some mining firms have had to consider importing liquified natural gas or accepting higher prices, which diminishes their project economics.

Renewables, although technically feasible, also face major barriers. Industrial parks such as Morowali and Weda Bay have significant solar potential; however, deploying solar PV at a meaningful scale for the operation requires coupling with battery energy storage systems (BESS) to ensure stable and continuous power for around-the-clock operation. This significantly raises the levelized cost of electricity (LCOE), making it less competitive with fossil-based power generation. Additionally, deploying large-scale solar PV requires significant land area, which can be a limiting factor, particularly in remote regions where most lands are protected forests and deforestation is an issue.

Hydropower is another renewable option that can supply around-the-clock dispatchable power. Although some regions in Sulawesi and Kalimantan have good hydro resources, they are often far from industrial hubs or lack the scale needed to support high-capacity operations. Nevertheless, a few companies, especially in North Kalimantan and central Sulawesi, have demonstrated the viability of using large-scale hydropower to power mining and smelting operations. These cases show that when feasible, hydropower can substantially reduce the emissions footprint. However, due to geographic and logistical constraints, hydropower is likely to remain a targeted solution, viable only in specific locations where suitable resources are available.

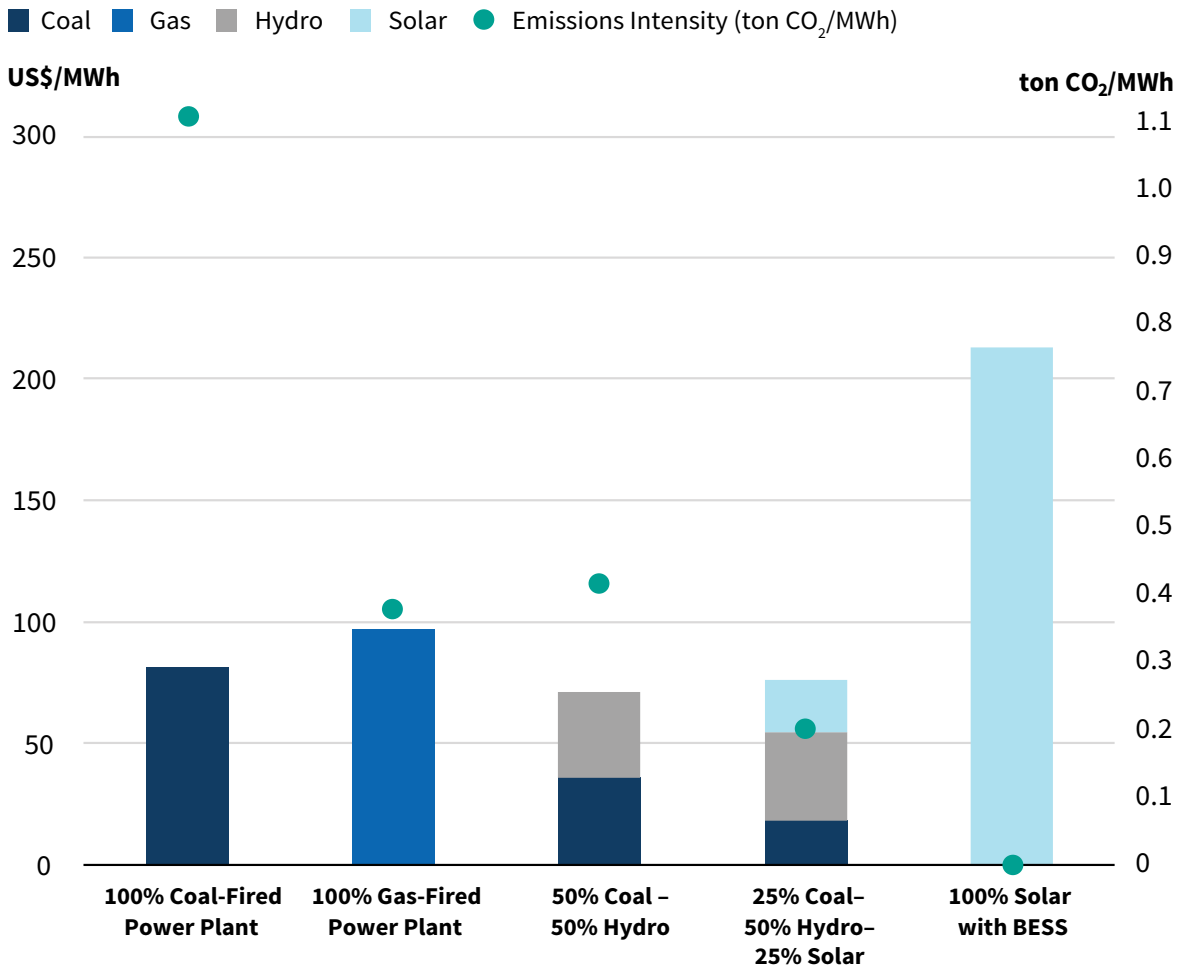


Comparative economics: key takeaways from LCOE

RMI analysis shows how 100 megawatts (MW) of captive coal at a nickel smelter facility in Sulawesi can be economically replaced with hybrid solutions (see Exhibit 9). The LCOE for a 100 MW subcritical coal-fired power plant with a coal price of US$100 per ton is approximately US$81 per megawatt hour (MWh), with an emissions intensity of 1.1 tons CO_2/MWh. If natural gas is used as the primary energy source with cost assumption of US$12/MMBtu — and assuming a secure, reliable supply and no methane leakage — the LCOE increases by about 20%, while the emissions intensity is reduced by more than 50%. It is important to emphasize that any methane leakage as low as 0.2% can significantly undermine the climate benefits, potentially making gas as environmentally harmful as coal. Therefore, careful management and monitoring of methane emissions are critical if gas is pursued.

Exhibit 9

LCOE and emissions intensity for different nickel smelter energy generation technologies for captive power



Note: All values are expressed in 2025 US$. Cost assumptions are based on the 2024 edition of the Technology Data Catalog (MEMR), using cost projections for 2030. The coal-fired power plant is modeled as a subcritical unit with a coal price of US$100/ton, and the gas-fired plant is modeled as a combined cycle gas turbine with a gas price of US$12/MMBtu and strict assumption that there are no methane leaks.

RMI Graphic. Source: RMI Analysis, MEMR

In scenarios where solar PV is fully utilized with BESS, the LCOE rises to more than 1.5 times the baseline, largely due to the need to oversize solar capacity and storage to ensure continuous power availability for the smelter's 24/7 industrial load. Despite the higher cost, this setup achieves near total decarbonization, with emissions intensity approaching zero.

Hybrid generation scenarios that integrate solar, hydro, and existing fossil-based assets may offer a near-term pathway to reduce emissions while maintaining system reliability. These configurations can deliver LCOEs that are 5%–15% more competitive than the coal-dominated baseline, primarily due to the low marginal cost of hydropower. However, such strategies must be approached with clear limits. In the context of a 1.5°C-aligned pathway, there is no longer room for new investment in fossil fuel infrastructure, including in so-called transition roles. Any hybrid approach must prioritize the rapid ramp-up of renewable generation and leverage existing fossil assets only as a diminishing backup, not as a structural feature

of the future energy mix. Moreover, the feasibility of hydropower integration hinges on the availability of reservoir-based systems, which remain geographically and environmentally constrained in many regions.

The emissions intensity of these hybrid scenarios also improves significantly, often ranging from 0.2 to 0.4 tCO_2/MWh, depending on the share of renewables in the mix. This demonstrates that partial decarbonization through renewables–fossil hybrids can offer cost savings and environmental benefits when hydro and solar resources are available.

Ultimately, even though full decarbonization using solar PV and battery storage is technically feasible, it remains cost-prohibitive for most smelter operations due to high capital and storage requirements. In the short term, hybrid solutions that integrate solar, hydro, and fossil fuels present a more pragmatic solution to lower emissions while maintaining system reliability. However, this should not be mistaken as a justification for sustained fossil investments. Any reliance on fossil generation could be structured as time bound and transitional, aligned with scaling cleaner power options.

Moreover, the hybrid configurations can also serve as a strategic hedge against future market risks. As international carbon regulations tighten, industrial producers will face increasing pressure to reduce emissions. Concurrently, Indonesia's evolving climate policy framework, such as the ETS mechanism, will impose rising costs on high-emitting operations. Investing in lower-emissions power systems today positions companies ahead of these regulatory shifts. Still, hybrid approaches should be viewed only as an interim solution. Aligning with net-zero pathways will ultimately require a full transition to fossil-free power systems.

Indonesia plans to expand ETS to captive coal power plants

In early 2023, the MEMR launched an intensity-based ETS for the power sector. The first phase, spanning 2023–24, covered coal-fired power plants connected to the electricity grid. By the first quarter of 2024, there were 146 coal-fired power plant units participating in the ETS. For the second phase, planned for 2025–27, the scheme will expand to include coal-fired power plants with capacities below 25 MW, gas-fired power plants, combined-cycle power plants, and captive coal power plants not connected to PLN's grid.

Toward grid integration: reducing captive power dependence

Connecting the industrial demand to the grid is an emerging pathway to reduce captive power reliance. PLN's Captive Power Acquisition Program (PCAP) has already set a precedent in integrating industrial power demand into the national grid, especially in Java where oversupply has become a structural challenge.[12] Through PCAP, PLN offers to supply the companies' industrial demand with grid electricity on a price premium basis. However, this initiative is currently still limited in several geographies, where grid infrastructure is mature and excess power is readily available.

In the RUPTL 2025–2034, PLN outlined specific projects for generation, transmission, and substations to supply high-voltage industrial customers. Among the numerous projects outlined, PLN highlights near-term initiatives in Sulawesi as examples. These include deploying National Mobile Reserve Margin plants, such as mobile gas turbine units, by 2025 to serve significant smelter hubs in Bantaeng (South Sulawesi), Andowia (North Konawe, Southeast Sulawesi), and Pomalaa (Kolaka, Southeast Sulawesi). By placing these

mobile units, each ranging from 50 to 100 MW, directly near smelter sites, PLN aims to minimize reliance on extensive new transmission infrastructure. Furthermore, approximately 1,200 MW of permanent generation capacity is expected to be operational in Sulawesi by 2027 to securely meet the increasing electricity demand from smelters.

To further support industrial growth, particularly in southern Sulawesi, PLN is significantly expanding the region's electricity backbone. A key initiative is the construction of a 275 kilovolt extra high voltage transmission line along the southern corridor. This line is an integral component of the broader Sulawesi super-grid program, extending from the central backbone down to the newly planned Bantaeng Smelter Facilities, scheduled for completion in 2028. These infrastructure projects exemplify PLN's strategic approach to integrating smelters' substantial energy demands into the national grid, as comprehensively detailed in the RUPTL 2025–2034.

Integrating smelters into the grid requires considerable infrastructure investments in both generation and network expansion. Although the RUPTL 2025–2034 does not explicitly state the cost of connecting smelters to the grid, it estimates the total investment cost to meet the overall demand (including smelters) of about IDR 2,780 trillion (approximately US$185 billion) for 10 years. Given the substantial capital requirements, PLN acknowledges that it cannot independently finance and construct all smelter-related infrastructure; instead, it plans to involve third-party investors and partnerships. Integrating energy-intensive smelters into the grid comes with several challenges including:

- **Demand Uncertainty and Investment Risk:** The uncertainty around smelter project timelines and their continuity poses risks, as infrastructure must be developed in anticipation of or concurrently with smelter startups. Delays or cancellations could lead to underutilized assets. PLN mitigates this by requiring firm commitments from smelter projects before significant investments proceed.

- **Technical Challenges (Grid Stability):** Smelter facilities have unique load characteristics, such as large power consumption and rapid demand fluctuations, which can disrupt grid stability. Addressing these technical issues requires advanced voltage control and compensatory equipment.

- **Project Execution and Timing:** Meeting aggressive industrial timelines is difficult, as many smelters aim to start operations between 2025 and 2027, compressing PLN's schedule to deliver necessary infrastructure. PLN employs rapid deployment strategies, including providing rental and mobile plants, relocating idle generation capacity, and accelerating project implementation.

Overall, the RUPTL 2025–2034 demonstrates PLN's comprehensive and strategic approach to supporting Indonesia's mineral downstreaming initiatives. By significantly expanding electricity generation and transmission infrastructure, PLN is effectively positioning itself to supply the rapidly growing energy demands of smelters. However, careful risk management is essential to navigate potential financial, technical, and regulatory challenges associated with these ambitious projects, ensuring reliability, sustainability, and economic prudence in grid development.

Toward Pathways for Competitive, Decarbonized Power for the Nickel and Aluminum Industries

Captive coal: a growing contradiction in Indonesia's decarbonization policy

Indonesia's nickel and aluminum industries have seen substantial growth in the past decade, driven by domestic demand and global supply chains transitioning toward cleaner technologies. However, this industrial expansion has increased the sectors' reliance on captive coal-fired power plants, particularly as new smelters continue to come online. Despite Indonesia's policy initiative to decarbonize coal power, the current regulatory framework, specifically Presidential Regulation No. 112/2022, exempts coal power plants that are linked to national strategic projects as well as industrial complexes. Although the regulation requires these captive coal plants to reduce emissions by a minimum of 35% within 10 years of operation and fully shut down by 2050, it does not prevent near-term expansion, potentially locking in decades of emissions.

This is illustrated in the RUPTL 2025–2034. which includes plans for approximately 6.3 GW of additional coal power capacity.[13] Although there is currently uncertainty regarding whether these represent entirely new projects or previously approved but delayed projects, their inclusion raises questions about Presidential Regulation No. 112, previously committed to halting the development of new coal power plants. Concurrently, captive coal plant capacity is projected to expand even further, with approximately 8.5 GW of new capacity by 2030, surpassing the additions for on-grid coal power. This underlines that captive coal is becoming the primary driver of coal-fired power plant growth, despite broader policy commitments shifting away from this type of power generation. Without addressing this gap, the industrial expansions risk being compromised by continued growth in coal dependency.

The challenge of transitioning industrial power systems

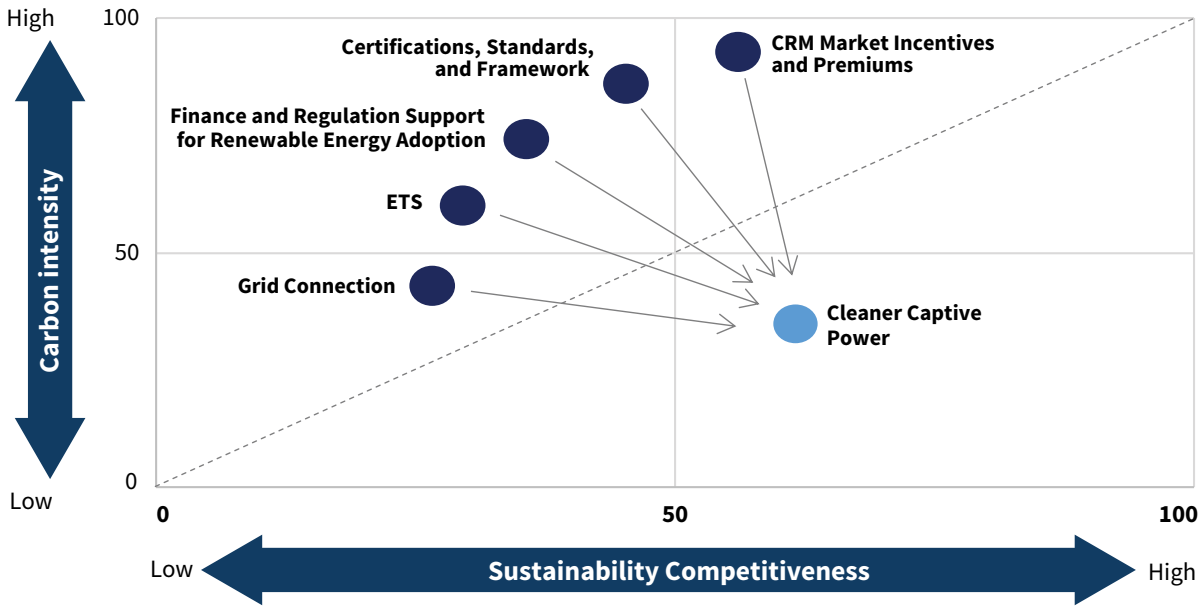
Decarbonizing the captive coal power in booming sectors such as nickel and aluminum is therefore critical. It requires navigating complex challenges: booming critical minerals industries, lack of market incentives for clean captive power generation, inadequate grid infrastructure, and limited clean energy options. Addressing these barriers is essential not only to streamline systemic changes but also to establish the country's position in global markets that prioritize low-carbon products.

A growing need for more accountable, verifiable, and established carbon accounting practices

As Indonesia's minerals processing sector scales rapidly, CRM producers in Indonesia face increasing pressure to demonstrate clear efforts to track, manage, and reduce their environmental footprint. As domestic demand in China slows, diversifying export markets — particularly in the EU — requires companies to strengthen their emissions verification processes. At the same time, increased public scrutiny of nickel producers highlights the need for more robust sustainability disclosures, following concerns over environmental performance. As Indonesia advances its carbon trading mechanisms, carbon accounting will be essential for both transparency and competitiveness to support regulatory compliance and effective market participation. Carbon accounting tools have proliferated, but they must be applied with rigor, verification, and strategic intent to drive meaningful emissions reductions.

Exhibit 10

Paths to decarbonize the power systems for nickel and aluminum industries



RMI Graphic

Exhibit 10 shows several pathways to support a cleaner captive power generation in Indonesia. Measures such as grid expansion will be critical to reducing industrial reliance on captive coal-fired power plants. PLN has initiated planning efforts to extend transmission networks to major smelter hubs; however, significant technical and coordination challenges remain. These include managing the inherent demand uncertainty of industrial growth, ensuring smelter load stability within a broader grid system, and synchronizing grid development timelines with the construction of industrial facilities.

Short-term alternatives, such as gas-fired generation, may be considered carefully, given the associated risks. Methane leakage across the gas supply chain poses a serious climate risk, potentially negating any emissions gains over coal. If gas is used, it must be tightly regulated, with robust infrastructure, transparent leakage monitoring, and market signals that reflect its true climate cost. Similarly, hybrid systems that combine renewables with fossil fuels may provide temporary emissions reductions and reliability benefits, especially where hydropower is available. However, these must be explicitly treated as interim arrangements, not structural components of a long-term decarbonization pathway.

For renewable energy to scale effectively in the industrial sector, a key technical challenge lies in coupling variable renewables with BESS to ensure round-the-clock power. Driving down the cost of renewable-storage systems will be essential to improve competitiveness. At the same time, regulatory bottlenecks must be addressed. Streamlining permitting, accelerating land approvals, and ensuring policy consistency are critical to unlocking investment and deployment at scale.

Enabling intentional market incentives and mechanisms for clean industrial growth will be key

Any industrial decarbonization strategy centers on the timely transition of fossil fuels while accelerating renewable integration. This requires addressing structural barriers through stronger market incentives, carbon pricing mechanisms, grid and storage infrastructure readiness, and institutional pathways that enable companies to access increasing shares of clean, affordable electricity.

Beyond infrastructure and pricing reform, enabling mechanisms such as direct power purchase agreements (DPPAs) and an ETS could offer additional levers to accelerate industrial decarbonization. A DPPA would allow companies to contract renewable electricity from off-site producers via the grid, offering greater flexibility and access to clean energy, particularly in regions where on-site generation is constrained. This model has already proven effective in attracting private-sector investment in several Southeast Asian countries, including Vietnam and Malaysia, which have piloted DPPA frameworks to enable corporate renewable procurement at scale. In Indonesia, the DPPA regulatory framework remains nascent, but advancing it would represent a key step toward expanding market access and investor confidence.

At the same time, PLN is exploring the operational and financial implications of power wheeling, an essential enabler for off-site renewable procurement, as referenced in the RUPTL 2025–2034. The utility has noted that ongoing discussions around the Draft Law on New and Renewable Energy and revisions to Electricity Law No. 30/2009 raise potential compliance and financial risks, particularly about how power wheeling could affect PLN's business processes and revenue streams. Although these concerns are valid, power wheeling remains a critical enabler for unlocking broader renewable access and must be addressed through balanced regulatory design. Parallel to this, ETS could reward verified emissions reductions and create price signals that incentivize cleaner industrial operations. Together, these market-based mechanisms could form part of a comprehensive policy package to support long-term decarbonization in Indonesia's industrial sector.

A case study: ETS implementation for China's captive power plants and aluminum sector

China implemented an ETS as a market-based tool to help achieve its climate targets of peaking emissions by 2030 and reaching carbon neutrality by 2060. China's ETS is designed as an intensity-based, output-allocated system rather than a fixed absolute cap. In its early phase, China's national ETS regulated emissions from the power sector, which includes electricity generation, combined heat and power, and captive power plants operated by industries.[14]

Before 2025, the aluminum sector was not directly regulated by the national ETS. However, the power plants serving those smelters were regulated. Hence, a large share of the aluminum sector indirectly fell under the ETS constraints via the power sector. Historically, aluminum smelting in China relied on captive coal power to access energy. By 2023, approximately 70% of energy to power aluminum smelting was coming from coal — or about 400 terawatt-hours of coal-fired power plants.[15]

In 2025, China officially expanded the ETS coverage to include aluminum smelters themselves.[16] Under the new rules, aluminum companies must account for their direct emissions from the smelting process, perfluorocarbon gases, and indirect emissions. Practically, this means an aluminum smelter now has two sets of compliance obligations: Its captive power plant must surrender allowances for emissions from power generation and process-related emissions from the smelter facility.

With this reinforced effort, China's aluminum sector is headed toward lower-carbon footing. Several observable trends have been demonstrated such as efficiency improvements and fuel and power source shifting. Although carbon prices remain relatively low, the ETS has helped reinforce the country's plan to push companies to retire captive coal-fired power plants and improve operational efficiency.

Simultaneously, data reporting and verification are critical. Indonesia should invest in a credible measurement, reporting, and verification system for emissions from mining and processing and encourage third-party audits. Certification schemes, modeled on global best practices, could help identify and reward producers with verifiably lower emissions. These tools will be essential for unlocking access to sustainable finance, export markets, and emerging green procurement frameworks such as the EU's CBAM and Battery Passport. Without such systems, Indonesian producers may find themselves sidelined in high-value supply chains.

Ensuring a just transition and leveraging market opportunities for low-carbon products

Decarbonizing the industrial power system cannot come at the expense of workers, communities, or environmental equity. Indonesia's Just Energy Transition Partnership underscores this approach to support equitable transitions away from coal, including labor retraining, job creation in clean energy sectors, and community resilience programs. Labor implications in mining and processing industries must be proactively addressed, as shifts toward low-carbon technologies could displace workers or

change skill requirements significantly. Structured retraining programs, targeted workforce planning, and clear pathways toward emerging clean industries are essential to maintain economic stability while driving decarbonization. Moreover, meaningful community engagement must be prioritized to minimize socioeconomic disruptions and incorporate local stakeholder voices into decision-making processes. Addressing environmental justice issues, particularly the risks related to air and water pollution in heavily industrialized regions, is also critical. Strengthening regulatory frameworks alongside initiatives such as the Just Energy Transition Partnership can ensure Indonesia's industrial decarbonization is inclusive, equitable, and environmentally responsible, effectively safeguarding vulnerable communities from bearing disproportionate costs.

Finally, market opportunities for low-carbon products are accelerating. While global green premiums are still developing, major buyers are beginning to offer long-term offtake agreements and preferential pricing for sustainable materials. For example, in the steel sector, RMI has developed a sustainable steel purchasing platform that aggregates corporate demand and helps establish suitable market mechanisms for both direct and indirect buyers.[17] In the aluminum sector, the First Movers Coalition is mobilizing early demand for near-zero aluminum, with commitments from global manufacturers to source low-carbon materials.[18] These initiatives reflect a broader trend: growing market signals that reward producers that can verifiably reduce emissions and demonstrate environmental performance.

Some players in Indonesia are already responding to this shift. Several nickel and aluminum producers have begun using hydropower to manufacture low-carbon products, an early indication that the country is positioned to enter the green metals space. However, for broader industry-wide transformation to take place, enabling conditions are essential. These could include policy clarity, improved access to clean power, credible emissions verification infrastructure, and support for communities and workers to help enable a just transition. By advancing on these fronts now, Indonesia can not only strengthen its leadership as the world's largest nickel supplier and important aluminum producer but also emerge as a global frontrunner in sustainable critical minerals production.

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