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INTEGRATING CIRCULAR ECONOMY PRINCIPLES AND PRACTICES IN INDONESIA'S NICKEL SECTOR: OVERVIEW, BENEFITS, AND ENABLING CONDITIONS

Policy Report

Laura Garcia Cancino, Hansika Agrawal, and Ben Baraga

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Authors

Laura Garcia Cancino, Hansika Agrawal, and Ben Baraga.

Executive Summary

Indonesia's Circularity Opportunity and Project Background

Indonesia is the world's largest producer of nickel ore and processed intermediates, a position built in little more than a decade. However, circularity practices in Indonesia's nickel-based industrial policy have been nascent and insufficient, resulting in missed opportunities to increase resource productivity, reduce exposure to shifts in commodity prices and battery chemistry, and protect market access as destination markets adopt requirements on carbon intensity and recycled content.

As part of the *Indonesia's Green Industrialization* project, developed by the Columbia Center on Sustainable Investment (CCSI) with support from Yayasan Visi Indonesia Raya Emisi Nol Bersih (ViriyaENB), this report examines how circular economy principles and practices can be integrated into Indonesia's nickel value chains and industrial parks where most processing takes place. Following the introduction and a conceptual **overview of circular economy** and its applications in nickel value chains (Section 1), this report sets out its **potential benefits** (Section 2) and assesses its **integration into Indonesia's nickel value chains** (Section 3), culminating in a **consolidated policy toolkit of recommendations** to close the gaps identified. The analysis covers process circularity in mining and industrial parks, and product circularity in electric vehicle (EV) batteries, assessed against three groups of enabling conditions: technical; policy and regulatory; and economic and financial. Batteries are the product focus because they are central to Indonesia's downstreaming (*hilirisasi*) ambitions. Companion publications in this project include a policy concept note on the mining–energy–industry feedback loop in Indonesia's nickel sector, a paper on financing Indonesia's green industrialization, and a project appendix compiling contextual information on Indonesia's mineral and energy landscape.

Why Circularity in Nickel Value Chains Matters, and Under What Conditions

Circular practices have the potential to improve resource productivity, hedge the capital intensity and long lead times of greenfield expansion, generate revenue from waste streams already accumulated, reduce energy and emissions intensity, lower site-level environmental risk, diversify the downstream economy away from dependence on a single commodity and a single battery chemistry, broaden and formalize employment, and improve worker and community health (Section 2). Each of these gains is contingent. Recovering nickel from batteries is itself electricity- and reagent-intensive, and, where the power supply is carbon-intensive, producing secondary nickel can consume more energy and generate more emissions than primary nickel. In Indonesia, where nickel processing runs substantially on captive coal, the energy and climate cases depend on power decarbonization proceeding alongside, which is the subject of the companion feedback loop report. Environmental gains depend on the intervention's full life-cycle impacts, social gains depend on designing in job quality and inclusion, and the economic case varies by intervention.

Resource Security and the Competitiveness Counterargument

Nickel ore grades fell nearly 40% between 2001 and 2020, and replacement is not keeping pace: Indonesia accounted for around 59% of global mined output in 2024 but attracted about 3% of global nickel-focused exploration spending. Meanwhile, the primary market has weakened, with prices down from their 2022 peak to roughly USD 15,000 to 18,000 per metric ton, and lithium iron phosphate (LFP) chemistries, which contain no nickel, taking roughly half the EV battery market.

A recurring counterargument to circularity in nickel value chains holds that since Indonesia's advantage in this value chain rests on continued demand for primary ore, that advantage erodes if nickel can be recovered from scrap wherever it is needed. The counterargument identifies a dependency but draws the wrong conclusion. Secondary supply will not fully displace primary supply, so the two will coexist for decades, and a position resting on sustained demand for newly mined ore is precisely the position worth diversifying away from. For instance, battery pre-treatment yields black powder from any cathode chemistry, so an industry built on that stage earns from the volume of batteries in circulation rather than from nickel demand specifically. Circularity is also broader than recycling: process circularity interventions such as advanced geometallurgy, resource-efficient extraction, and by-product recovery lower the cost and waste intensity of primary production itself.

Process Circularity Is Advancing, Product Circularity Has Barely Begun

Process circularity is advancing while product circularity has barely begun (Section 3). Indonesia has built seven high-pressure acid leaching (HPAL) plants since 2021, with 14 more permitted or under construction, and current, permitted, and planned facilities imply on the order of 275 million metric tons of tailings. Filtered tailings are used in all projects, but the technique is being applied at throughputs and in wet, seismic conditions beyond where the technology has been proven; a recent failure halted a substantial share of national HPAL capacity. Tailings storage is the binding constraint on process circularity. Slag valorization, by contrast, already works, with operators substituting slag for road stone and converting it into bricks under its reclassification as waste registered as non-B3 (that is, non-hazardous, non-toxic). However, the reclassification's effect is limited in practice: reuse beyond the generating operator's concession depends on a separate permit, so slag valorization is revenue-positive within a firm but not reliably tradable between firms. On the product side, battery projects are at very early stages, reverse logistics is nascent, and licensed recyclers cluster on Java island. A measurement gap compounds this. Whether a retired battery pack can enter a second life depends on its state of health, which must be measured for each unit, and Indonesia lacks a grading procedure to do so.

Circularity Regulation Exists but Lacks Specificity and Depth

Indonesia's policy and regulatory frameworks governing circularity frequently state obligations without the detail that makes them operative in practice or easily enforceable (Section 3). The tailings reprocessing regime, for example, already requires operators to record the volume, element, and grade of processing residues and to pursue utilization, yet no methodology or minimum parameter set is specified; the utilization test is self-assessed, the resulting data is not disclosed, and the mandatory retreatment study that applies to gold residues has no nickel equivalent. The obligation therefore yields no usable data.

A second constraint reinforces the first: because residues are classified as hazardous waste, obtaining a sample for research requires an environmental permit, so data that operators are not required to produce to a usable standard is also difficult for others to generate independently. This gap helps explain mining's absence from the National Circular Economy Roadmap, which identified priority sectors partly based on data availability; including mining would require prior characterization and disclosure. However, disclosure is not only a matter of accountability: without data on residue composition, volumes, and treatment routes, policy cannot be designed to match actual conditions or updated as they change. Dam regulations similarly cover permitting but not engineering criteria, with no seismic safety factors, setback distances, or mandatory consequence-based design.

Batteries remain defined as hazardous waste. The governing framework specifies disposal and establishes no pathway for collection, reuse, or recycling. Producer responsibility exists in general waste law but targets household streams and creates no battery-specific take-back, financing, or target obligations. Two regimes divide by source—industrial B3 waste and household B3-containing waste—and a battery crosses between them at end of life, with no instrument establishing continuity of obligation across the handover. Though warranted on hazard grounds, this classification carries a cost consequence: permits and licensed handlers are required at every step, licensed capacity is concentrated in Java, and the compliant route is therefore most costly where formal capacity is thinnest, a structural driver of informal handling. The gap remains downstream since there is no pathway for second-life repurposing, no testing or certification regime for repurposed batteries, no demand-side measure, and no tariff classification for used batteries. Moreover, producer ownership models, which keep the producer responsible for the battery across its life and for its durability and recovery, remain unaddressed. Indonesia regulates public battery swapping stations as electricity supply infrastructure, but nothing addresses battery ownership across multiple cycles.

The Enforcement, Accountability, and Coordination Gaps

Frameworks are often under-implemented and under-enforced across a site's operating life and at closure. Site reclamation is an example of this gap, where companies must report annually and must deposit guarantee funds to ensure land is restored regardless of their solvency, but there is no standardized inspection timeline, no framework for assessing what is submitted, and as of 2018, more than 60% of concession holders had not deposited the required funds at all. The obligation exists; the money largely does not. Processing and refining facilities sit outside the guarantee fund regime altogether, so smelter and HPAL plant closures depend on whether the operator is solvent at the time, and corporate structures can strand those liabilities in undercapitalized entities, since limited liability carries no environmental carve-out. Accountability is weak in two further respects. Reporting runs to the government but not to the public, and international benchmarking finds Indonesia scores negatively across virtually all mine waste disclosure categories. Additionally, the Indonesian government distributes responsibility for circularity across mining, environment, industry, investment, and planning authorities, with no single point of coordination.

Some Interventions Pay Today, Others Cannot Yet

The economic case is uneven across different circular economy interventions (Section 3.3). In Indonesia, slag valorization, water reuse, and industrial symbiosis are either revenue-positive or near-viable; integrated battery recovery and tailings reprocessing are not, and will not be until volumes and markets develop. Policy compounds these issues by neither pricing disposal nor rewarding recovery, and by taxing domestically recovered material in transactions exempt from import duties on primary material. Infrastructure is concentrated and uneven: industrial parks are organized around primary processing rather than circular material loops, collection capacity is absent across most of the archipelago, and tailings storage capacity lags HPAL expansion. On skills, worker safety is the most acute dimension, with roughly 90 workplace accidents and dozens of fatalities recorded in recent years; specialized tailings and hydrometallurgical competencies remain scarce.

The Regional Dimension of Circularity

Transport dominates battery recycling economics, accounting for 30% to 70% of total recycling cost, while hydrometallurgical processing is profitable only at high throughput. Attempting to develop a full recycling value chain within Indonesian borders evidences the tension between these requirements, since proximity to retirement points argues for distribution across the archipelago while scale argues for concentration. Developing it at a regional scale resolves the tension through aggregation. Collection cannot be relocated, since EV batteries retire where vehicles are used, so the question is where material goes once collected and how it moves. The regional nickel corridor that already exists in the Indonesia–Philippines (IndoPhil) arrangement, built around the primary chain, could be extended to include EV battery recovery.

The Risk of Regulating in a Vacuum

Policy instruments written without regard to on-the-ground economic and infrastructure conditions carry a particular risk. Instruments that are easy to adopt and easy to verify can leave a government with the sense that it has done what was needed, while little changes in practice. For instance, a producer responsibility fee can be paid, a battery passport filed, and a reporting duty met, and collection and recovery rates can still not move, because what is measured is the action taken rather than the result.

Policy instruments change things like who pays and who reports, not what is physically possible. What makes an instrument work is the set of conditions around it, which is why this report offers sequenced recommendations that account for the state of enabling conditions on the ground and each policy instrument's fitness to the intended circularity goals.

Next Steps for Implementation

Recommendations are consolidated in the Policy Toolkit Summary (Table 3), grouped by enabling condition and by priority level. These measures are designed to operate as a package rather than as a menu of policy options to pick and choose. Several are ineffective in isolation because they presuppose conditions that other measures establish.

The priority levels in the Policy Toolkit reflect that dependency rather than relative importance. Measures assigned high priority concentrate on specification, disclosure, and classification: they are the conditions on which other measures depend, not necessarily the measures with the largest effect. Those assigned medium priority, including regional integrated battery recovery, tailings reprocessing, and second-life markets, depend on volumes, data, and institutional capacity that do not yet exist.

List of Acronyms and Abbreviations

AMCAP-IV	ASEAN Minerals Cooperation Action Plan 2026–2030
AMD	acid and metalliferous drainage
AMDAL	environmental impact assessment (*Analisis Mengenai Dampak Lingkungan*)
ASEAN	Association of Southeast Asian Nations
B3	hazardous and toxic (waste) (*Bahan Berbahaya dan Beracun*)
BaaS	batteries-as-a-service
BAPPENAS	Ministry of National Development Planning (*Badan Perencanaan Pembangunan Nasional*)
BAT	Best Available Technology
BESS	battery energy storage system
CETEM	Center for Mining Technology (Brazil) (*Centro de Tecnologia Mineral*)
CO_2	carbon dioxide
CO_2-eq	carbon dioxide equivalent
CSIR	Council for Scientific and Industrial Research (South Africa)
DC	direct current
EPR	extended producer responsibility
ERT	Electrical Resistivity Tomography
ESS	energy storage system
EU	European Union
EV	electric vehicle
GGGI	Global Green Growth Institute
GHG	greenhouse gas
GISTM	Global Industry Standard on Tailings Management
GJ	gigajoule
GR	Government Regulation (*Peraturan Pemerintah*)
GWh	gigawatt-hour
HPAL	High-Pressure Acid Leaching
IEA	International Energy Agency
ILO	International Labour Organization
IndoPhil	Indonesia–Philippines (Nickel Corridor)
KGNDTF	Korean Green New Deal Trust Fund
kg	kilogram
KPI	key performance indicator
LFP	lithium iron (ferro) phosphate
MOU	memorandum of understanding
MW	megawatt

Permen LHK	Ministry of Environment and Forestry Regulation (*Peraturan Menteri Lingkungan Hidup dan Kehutanan*)
PRO	producer responsibility organization
PT	Limited Liability Company (*Perseroan Terbatas*)
R&D	research and development
RAN-ES	National Roadmap and Action Plan: Circular Economy Indonesia 2025–2045 (*Peta Jalan dan Rencana Aksi Nasional Ekonomi Sirkuler 2025–2045*)
RISE	Resilient and Inclusive Supply Chain Enhancement (Partnership, World Bank)
RKAB	Work Plan and Budget (*Rencana Kerja dan Anggaran Biaya*)
RKEF	Rotary Kiln-Electric Furnace
SIMBARA	Mineral and Coal Information System (*Sistem Informasi Mineral dan Batubara Antar Kementerian/Lembaga*)
SNI	Indonesian National Standard (*Standar Nasional Indonesia*)
SPV	special purpose vehicle
UNIDO	United Nations Industrial Development Organization
USD	United States dollar

Introduction

Indonesia's nickel sector sits at the intersection of two fast-moving policy agendas: (i) domestic downstreaming and green industrialization, increasingly organized around industrial parks and integrated processing hubs; and (ii) global energy transition supply chains, in which critical minerals, particularly nickel, have become a strategically important input. In 2024, Indonesia produced roughly 2.2 million metric tons of nickel (mine production) out of an estimated global total of 3.7 million metric tons, and it held an estimated 55 million metric tons of nickel reserves—positioning it as the dominant producer and one of the most resource-endowed countries in the global nickel economy.[1] This supply-side prominence coincides with demand-side shifts: the International Energy Agency (IEA) projects that, in a scenario consistent with rapid clean energy deployment, clean energy technologies could account for around 60–70% of global nickel demand by 2040 and electric vehicles (EVs) and storage to overtake stainless steel as the largest end-use of nickel.[2] Together, these trends make Indonesia's choices about how nickel is extracted, processed, and integrated into downstream value chains crucial not only for national green industrialization purposes, but also for the greenhouse gas (GHG) emissions profile of the global energy transition.

At the same time, the current trajectory of nickel industrialization poses sustainability risks, particularly in industrial parks where most processing is taking place and additional capacity is being built. Energy demand for refining and smelting is substantial and, in practice, mostly met through captive coal-fired power plants.[3] This situation creates a tension between accelerated energy transition commitments and industrial expansion. This tension is relevant given Indonesia's stated long-term decarbonization direction, including a net-zero target by 2060 and a green industrialization strategy.

As part of the *Indonesia's Green Industrialization* project, developed by CCSI with support from Yayasan Visi Indonesia Raya Emisi Nol Bersih (ViriyaENB), this report responds to that tension by examining how circular economy principles and practices can be integrated into Indonesia's evolving green industrial policy throughout the nickel value chain and the industrial park model, which increasingly structures nickel processing and downstream manufacturing. This policy report offers an evidence-based, policy-oriented assessment of opportunities and challenges for embedding circularity into nickel-related green industrialization, with a practical focus on the enabling conditions of a circular economy available to Indonesian policymakers and nickel value chain stakeholders.

The core premise is that circularity is not only an environmental value-add: when strategically designed, it can function as part of a broader industrial policy that improves resource productivity, reducing costs and liabilities associated with waste and pollution, supporting learning and innovation in processing hubs, and helping Indonesian producers remain competitive as major markets tighten requirements on GHG emissions and circularity.

Following the introduction and a conceptual overview of circular economy (Section 1), the report sets out its **potential benefits** (Section 2) and assesses Indonesia's current **state of play against circularity best practice across three enabling conditions** (Section 3), culminating in a **consolidated policy toolkit of recommendations** to close the gaps identified.

In recognition of the importance of mineral–industrial energy decarbonization and sustainable finance alongside circular economy interventions in fostering Indonesia's green industrialization and sustainable development based on nickel value chains, this policy report has two companion pieces: a policy concept note titled *Mining–Energy–Industry Feedback Loop in Indonesia's Nickel Sector: Structure, Benefits, and Enabling Conditions*[4] and an applied research paper titled *Financing Indonesia's Green Industrialization: System Pathways, Structural Diagnosis, and Tailored Solutions*.[5]

Contextual information on Indonesia's current mineral and energy landscape is compiled in the project appendix: *Indonesia's Green Industrialization: Landscape and Trends in the Energy Sector and Critical Minerals Value Chains, with a Focus on Nickel*.

Rationale and Scope: Circularity in Nickel Value Chains and Industrial Parks

Circular economy integration has become increasingly material to market access and industrial competitiveness in battery supply chains. The European Union (EU)'s Batteries Regulation, for example, establishes minimum recycled content requirements for active materials in EV and industrial batteries, including explicit thresholds for nickel, alongside a wider architecture of documentation, due diligence, and GHG emissions-related provisions.[6] Such regulatory developments raise the strategic value of building credible secondary material pathways (including recycling and recovery) and of reducing the life-cycle footprint of primary processing, both of which can be supported through circular economy policy, technology, and governance. Moreover, embedding circularity practices across metals value chains in energy transition contexts has, in specific cases, generated additional revenue streams and increased revenue for companies implementing them.[7]

For Indonesia, where downstreaming aims to capture more value domestically, circularity can help ensure value creation remains resilient to emerging trade and regulatory headwinds. Two complementary categories of circular economy policy are relevant to circularity in Indonesia's nickel value chain:

1. **Process circularity:** This report assesses opportunities for process circularity at the upstream and midstream segments of the nickel value chain as follows:
   - **Extraction:** circular practices at the mine site, including opportunities to reduce material losses, manage and valorize waste streams where feasible, and strengthen water usage optimization and land recovery.
   - **Processing in industrial parks:** circular practices within industrial parks, particularly around waste and by-product management, industrial symbiosis, water circularity, and energy circularity and efficiency, recognizing that industrial parks can enable shared infrastructure and co-location synergies but can also concentrate environmental and energy system risks.
2. **Product circularity**: The analysis focuses on opportunities for product circularity in the downstream segment of nickel value chains and prioritizes nickel used in batteries, reflecting batteries' centrality to Indonesia's downstreaming and green industrialization ambitions, as well as projected growth in nickel demand from clean energy technologies. Product circularity in this context includes the enabling conditions for collection, sorting, safe handling, transport, and recovery of nickel from nickel-bearing battery materials, and the policy tools that can accelerate the emergence of domestic secondary supply.

Nickel use in other sectors falls outside the scope of this report. For instance, nickel use in wind turbines and other renewable energy technologies is typically embedded in the steel value chain and not recovered separately for product-level circularity practices, implying a different (steel-specific) circularity pathway.[8] Other alloy-based applications of nickel, such as aviation and industrial machinery, similarly limit nickel-specific recovery routes, making these alloys part of distinct value chains that fall outside the nickel value chain's scope. Lastly, electroplating/semiconductors are excluded, as they fall outside the report's downstream focus on green industrialization and energy transition–relevant value chains. These boundaries ensure the analysis remains actionable for the principal policy question at hand. One exception is made. Nickel-bearing steel in wind is excluded above because the nickel is not separately recoverable at end of life. That constraint does not apply to ownership-based models, which act on the metal in the asset rather than on its separation from the product; the wind case is addressed in Box 2, in the context of Metals-as-a-Service (MaaS).

While cross-border circularity will be important for scale on a regional basis, particularly through trade rules that enable secondary material markets, intellectual property frameworks that support diffusion of circular technological innovations, and harmonized classifications for waste, by-products, and secondary raw materials, this report centers on circularity within Indonesia's domestic downstreaming agenda. A regional lens is recognized as a strategic opportunity and enabling condition, both from a policy and economic perspective, but not mapped comprehensively.

1. Circular Economy and Its Applications in Nickel Value Chains

The Indonesian Ministry of National Development Planning's (*Badan Perencanaan Pembangunan Nasional,* BAPPENAS) *National Roadmap and Action Plan: Circular Economy Indonesia 2025–2045* (RAN-ES) indicates the country's adherence to two standard circularity frameworks: the Ellen MacArthur Foundation's three principles, and the 9R framework. The plan explicitly acknowledges that circular economy goes beyond waste management and recycling and lists the Ellen MacArthur Foundation's three principles:[9]

1. Eliminating waste and pollution.
2. Keeping resources and products in use within the economic cycle for as long as possible.
3. Building regenerative ecosystems.

The circular economy **eliminates the concept of waste** by prolonging the use of products and regenerating the viability of resources used to manufacture them.[10] Not only does this limit value leakage, but leads to value creation and capture.[11] Value is multifaceted and benefits all stakeholders in the circular economy: social value from job creation and pollution reduction, economic value from cost reduction and new revenue streams, environmental value from ecosystem protection, and reputational value from investor attraction and customer loyalty.[12]

The 3R framework of "reduce, reuse, recycle" commonly associated with the circular economy has its own value considerations.[13] Reduction and reuse are more valuable than recycling, as the latter, in certain cases, can only be done only a finite number of times due to degradation of materials with each occurrence; ironically, recycling tends to be prioritized by circular economy policies worldwide.[14] More "R" practices have been added over time, growing from three to ten,[15] an expansion the RAN-ES reflects in adopting a 9R framework that covers ten initiatives, R0 (Refuse) through R9 (Recover) (Figure 1).[16]

9R Principles	Definition	Examples of Application
R0 Refuse	Avoiding redundancy in the creation of products with the same function.	Removal of formwork using modular and precast concrete in construction projects.
R1 Rethink	Using products more intensively.	Utilizing digital platforms by businesses to facilitate product sharing.
R2 Reduce	Improving production efficiency and product utility by using fewer materials.	Creating clothing patterns with cutting processes designed to reduce fabric waste in the garment industry.
R3 Reuse	Reusing products that are still usable without altering their function.	Using wearable clothing and household textiles (curtains, tablecloths, bedding) from donations or resale.
R4 Repair	Repairing damaged products.	Repairing electronic products at service centers.
R5 Refurbish	Refurbishing products, typically older products, to restore their functionality.	Reusing old wooden doors from older buildings that are sanded and repainted for use in new buildings.
R6 Remanufacture	Using components from old, non-functional products in new products with the same function.	Retrieving Smart Meters from PLN (State Electricity Company) customers to replace worn-out components and then reusing them for other PLN customers.
R7 Repurpose	Repurposing non-functional products for use in a different function.	Processing food waste into animal feed.
R8 Recycle	Processing materials to produce the same material (with the same or lower quality).	Recycling plastic packaging into secondary raw materials (plastic pellets/ chips) used to produce new plastic packaging.
R9 Recover	Converting materials into energy.	Recovering plastic packaging into energy in the form of oil, RDF, or gas.

Figure 1. Definitions and applications of the 9R principles (R0-R9) in Indonesia
Source: BAPPENAS (2024).[17]

As shown in Figure 1, more than simply reducing waste through recycling, a *circular* economy starts upstream, in rethinking and reducing the resources we use, cascading down the value chain.[18]

The concepts of process and product circularity complement the 9R framework, rounding out the definition of circular economy and narrowing the set of circularity interventions.[19] In the mining and metals context, **process circularity** means “reducing emissions and minimizing, reusing, and ultimately eliminating waste at mine sites and in metal industries”; **product circularity** means “repairing, reusing, and remanufacturing equipment, and harvesting and recycling metals indefinitely through product design and collection processes.”[20] The distinction tracks the mineral value chain—process circularity upstream and midstream, product circularity downstream—and narrows each scope to keep the focus on the feasibility and scalability of existing efficiency practices.

Process circularity already exists in modern mining and mineral processing business models. As a core part of their work, companies maximize profit by increasing valuable mineral yield, reducing energy and water use, and extending the lifespan of equipment as long as possible.[21] Circularity practices and cost-saving measures can be one and the same—for instance, pre-extraction geospatial modeling allows the mining company to be certain to hit a high-yield deposit, reducing the amount of waste generated in the process. The practice is a form of **advanced geometallurgy**, and extends to creating 3D models of the piles of so-called “waste” to identify valuable byproducts to be sold for additional revenue.[22]

Beyond economic value, process circularity captures social, environmental, and reputational value for mining and processing operations. Acid and metalliferous drainage, caused by improper mining waste management, has been identified to be the second-biggest global environmental challenge after climate change.[23] Tailings dam collapses pose another high risk—the 2019 Brumadinho dam failure killed at least 259 people in Brazil, alongside extensive environmental, social, and economic damage.[24] Tailings failures also happen in Indonesia,[25] a risk that needs to be mitigated, since the dominant high-pressure acid leaching (HPAL) process generates roughly 133 metric tons of tailings per metric ton of nickel.[26] Process circularity practices like **filtered tailings**—dewatering mine waste instead of flooding them in a pond—help mitigate this risk, and provide co-benefits such as construction material and water reuse.[27]

Improving resource efficiency requires research and development (R&D), as not all technology is market-ready today. Circularity best practices are far from being arcane or unrealizable; indeed, they are the logical next step of current operations. Beyond pivoting away from dangerous dams, companies are developing ways to **re-mine tailings** to address demand concerns while maintaining safe storage.[28] An important aspect of process circularity, thus, is the participation of companies in consortiums, co-funding, and knowledge transfer to facilitate technological breakthroughs and bring them to market.[29]

Following the Ellen MacArthur Foundation’s circular economy third principle replicated by RAN-ES, process circularity also extends beyond the operating life of a site. **Post-mining land use, rehabilitation, and reclamation** are how a mining operation regenerates the natural systems it has disturbed rather than leaving them degraded, which is what makes them circularity measures and not only closure obligations. Reclamation is the physical work of returning disturbed ground to a stable, safe condition. Rehabilitation goes further, restoring ecological function so that the site supports living systems again. Post-mining land use is the end state those efforts serve, whether nature restoration, sustainable agriculture, renewable energy generation, or community-oriented purposes.[30]

Product circularity, in the context of this report, focuses on the EV battery value chain. From 2010 to 2022, the allocation of nickel resources to battery production rose from just under 5% to nearly 20%; at the same time, the ratio of loss to recovery in nickel utilization is only 4:1.[31] Rising battery demand and the shortfall in nickel recovery signal a need for circular economy strategies, including reuse, end-of-life recovery, and rethinking business models through servitization.[32] Because batteries retain substantial capacity after being retired from vehicles, reuse in less-demanding applications should precede end-of-life chemical recovery of the nickel they contain (Section 3.1).

Battery recycling, though less valuable than reusing, can be implemented creatively to capture as much value as possible. For example, companies use the energy present in retired batteries to help power their recycling process.[33] This not only saves costs for the business, but also avoids a major concern for Indonesia’s green industrialization strategy: downstreaming is highly energy intensive.[34] The synergies between battery recycling and battery technology production more broadly illustrate the role of product circularity in the mining–energy–industry feedback loop.[35]

Rethinking business models entirely, such as through **servitization**, is another core piece of product circularity. Battery swap schemes allow EV owners to lease their batteries: depleted batteries are swapped for new or recycled ones, rather than dumping them and buying new ones.[36] Swap schemes can be structured so the producer retains ownership, and it is the retention rather than the swapping that changes design incentives. Even mining and metals companies have a role to play—their expertise in validating metal quality in existing stocks lends confidence to manufacturers looking to capture the secondary metals market.[37]

As the battery industry moves away from nickel as a core component of EV batteries,[38] product circularity best practices can be applied broadly, including to lithium iron phosphate (LFP) batteries. A sustainable green industrialization strategy requires diversification, and product circularity can be a method of building capacity in non-nickel sections of the critical minerals value chain as well.[39]

Process and product circularity describe one loop. Nickel recovered from tailings and slag enters the same value chain that returns nickel to smelters through battery collection, and interventions confined to one end forfeit value at the other. Indonesia's presence across that full span, from mine site to cathode precursor, is what makes both relevant to its industrial strategy.

2. Overview of Potential Benefits of the Circular Economy in Indonesia's Nickel Value Chains

Circular economy strategies in nickel value chains, more than serving as a waste management tool, offer a way to rethink how value is created, retained, and redistributed, by keeping nickel and its by-products in productive use for longer, recovering value from mine waste, tailings, slag, and end-of-life batteries, and reducing dependence on new primary extraction. This matters for Indonesia, with a downstreaming agenda increasingly oriented toward battery-grade nickel.[40] Circularity can generate economic benefits and strengthen industrial resilience (Section 2.1), reduce environmental harm (Section 2.2), lower energy demand (Section 2.3), and generate more localized social benefits (Section 2.4).

These four dimensions are interdependent, and several of the gains are contingent rather than automatic, as noted throughout. For example, the net energy and emissions savings benefits described in Sections 2.2 and 2.3 depend on coupling secondary production with renewable energy systems, because hydrometallurgical recovery of battery nickel is itself electricity- and reagent-intensive. Under prevailing global energy mixes, secondary nickel can lag primary nickel on energy and emissions even while remaining more economically attractive.[41] In Indonesia, where nickel processing is mostly powered by captive coal-fired plants, this conditionality is particularly relevant. Both the energy and emissions savings co-benefits of nickel circularity are tied directly to power decarbonization.[42]

2.1 Economic and Industrial Co-Benefits

Integrating circularity into mineral value chains can improve resource productivity and long-term economic resilience. At the macro level, the transition to a circular economy has been estimated to generate on the order of USD 4.5 trillion in additional global economic output by 2030, by decoupling growth from primary resource consumption.[43] For nickel producers specifically, building a secondary supply stream can act as a partial hedge against the high capital expenditure and long lead times of greenfield projects, which is significant as Indonesian HPAL plants represent multi-billion-dollar investments, and the IEA estimates recycled nickel could meet a growing share of demand—on the order of 12% by the early 2030s, rising toward a quarter or more by 2040 under pledge-based scenarios.[44]

Specific value can be unlocked by valorizing existing waste streams, although recoverable value is highly site- and technology-dependent and should not be assumed uniform across deposits. As an illustration of scale, copper tailings generated globally in 2022 have been estimated to contain recoverable copper worth between USD 74 billion and USD 297 billion at prevailing prices.[45] Nickel mine tailings and slag also retain metal, though its recoverability depends on residue chemistry and processing route, and Indonesian smelter slag is already being converted into saleable construction material (Section 3.1).

The case for recovering that value is strengthened by what is happening to primary supply. Nickel ore grades have fallen nearly 40% between 2001 and 2020 (Section 3.1.2), and the decline is not being offset by replacement: Indonesia accounted for around 59% of global mined nickel output in 2024 but attracted only about 3% of global nickel-focused exploration spending, with exploration investment in both Indonesia and the Philippines well below its 2010 to 2016 levels.[46] As primary ore grades decline,[47] the relative concentration of value in secondary sources rises: end-of-life electronics, for example, can be far richer than primary ore for some metals.[48] Secondary supply can therefore reduce nickel -security risks. By establishing secondary nickel supply closer to its battery manufacturing hubs, Indonesia could reduce exposure to price volatility and reinforce the domestic value chain it is building.[49]

For Indonesia, these dynamics matter directly to the downstreaming agenda: circularity can help ensure that domestically captured value is more resilient to trade and regulatory headwinds (such as requirements on recycled content and carbon intensity in destination markets), while front-runner companies that capture revenue from by-products and secondary materials can improve competitiveness. However, not every intervention is revenue-positive in the near term; the economic case varies by material, technology readiness, and logistics, a nuance developed further in Section 3.3.

A common counterargument for this framing is that, if nickel can be recovered from scrap wherever it is needed, buyers have less reason to source it from Indonesia, so since today Indonesia's advantage rests on the continued need for primarily mined ore, implementing circularity practices would erode that advantage.[50] Even though this counterargument identifies a dependency, it misreads the scope. Secondary supply will never fully obviate the need for primary supply, so they will need to coexist. Moreover, a position resting on sustained demand for newly mined ore is precisely the position worth diversifying away from. Circularity is also considerably broader than recycling: advanced geometallurgy, resource-efficient extraction, and by-product recovery lower the cost and waste intensity of primary production itself. If the infrastructure and competence built for recovery, characterization, separation, and hydrometallurgy are metal agnostic, where possible, circular economy approaches can help diversify the sector.

This diversification case is made more urgent by recent headwinds in the primary nickel market, which expose the risk of an economy concentrated on a single commodity tied to a single battery chemistry and a concentrated set of buyers. Nickel prices fell from a spike of over USD 100,000 per ton in early 2022 to roughly USD 15,000–18,000 by late 2024 and through 2025, against a backdrop of structural oversupply driven substantially by Indonesian expansion.[51] At the same time, demand for nickel-bearing chemistries is being eroded by the rapid rise of lithium iron phosphate (LFP) batteries, which contain no nickel: LFP grew from under 10% of the EV battery market in 2020 to roughly half by 2025, the nickel-manganese-cobalt share in China fell to around 18% over the first nine months of 2025, and carmakers such as Tesla and BYD have shifted significant volumes to LFP.[52] Strikingly, more than 90% of EVs sold in Indonesia in 2025 used LFP rather than nickel-based batteries.[53] These pressures do not negate nickel's long-term role in the energy transition, but they illustrate the volatility of a value chain dependent on one chemistry and a concentrated set of buyers. Circular economy practices, such as recovering, refurbishing, and reprocessing nickel and its by-products, and developing servitization and second-life markets, offer a way to diversify economic activity and employment within the sector and build resilience against precisely this kind of price and demand shock, generating value that does not depend on continually expanding primary output.

Battery recovery offers a particular form of that diversification, because its first stage is not chemistry-specific. Pre-treatment, meaning discharge, dismantling, crushing, and sorting, yields black powder, a mixed intermediate containing lithium, nickel, and other metals, and the operation is substantially the same whatever cathode chemistry enters it.[54] An industry built on that stage, therefore, earns from the battery stock in circulation rather than from nickel demand specifically, which is the exposure that the LFP shift described above creates. The opportunity depends on batteries returning in volume, which in Indonesia they do not yet (Section 3.3.1). The point is nonetheless that a recovery industry is exposed to how many batteries retire, while a primary nickel industry is exposed to which chemistry wins, and those are different risks. Section 3.1.4(B) sets out what a staged entry into that industry would involve.

2.2 Environmental Co-Benefits

The environmental case for circularity in mineral value chains is significant for climate mitigation. The extraction and processing of materials and fuels are estimated to account for roughly half of global GHG and more than 90% of land use–-related biodiversity loss and water stress.[55] Recycling energy transition minerals—nickel, cobalt, and lithium—generates, on average, around 80% fewer GHG emissions than primary production from mining, which the IEA estimates could translate into a cumulative reduction of roughly one-third in production-related emissions for these minerals as recycling scales to 2040.[56]

For instance, primary nickel production is highly energy-intensive, with GHG intensities ranging from roughly 18 carbon dioxide equivalent per kg (CO_2-eq/kg) for ferronickel to nearly 70 kg CO_2-eq/kg for nickel pig iron, driven largely by coal and coke use. While HPAL lowers direct combustion emissions significantly, it is reagent- and electricity-intensive.[57] Recovering nickel from end-of-life batteries or scrap can avoid the process of smelting and refining virgin ore, thereby avoiding a substantial share of the emissions burden of primary mining and processing.

Circular practices can also mitigate large-scale environmental risks specific to nickel mining and processing. For instance, HPAL generates roughly 133 tons of tailings per ton of nickel, and the cumulative tailings projected from current, permitted, and planned facilities run to 275 million tons.[58] Reprocessing and re-mining nickel tailings, safer filtered-tailings storage, and slag valorization can reduce volumes of stored waste while addressing long-lived hazards such as acid and metalliferous drainage and catastrophic dam failure, including through liquefaction of filtered tailings stacks,[59] which have already produced fatal incidents in Indonesian nickel operations (Section 3.1).[60] These benefits are conditional: secondary nickel recovery processes—particularly hydrometallurgical routes—carry their own emissions, add reagent consumption, and process water demand of its own, so environmental gains should be assessed on a life-cycle basis.[61]

2.3 Energy Savings Co-Benefits

Circularity can reduce the energy intensity of mineral value chains, including nickel, by preserving the embodied energy of metal already in circulation. Primary nickel is highly energy-intensive to produce: life-cycle assessments report primary energy demand on the order of 300–600 GJ per ton of contained nickel.[62] Recovering nickel from end-of-life batteries or scrap can avoid the process of smelting and refining virgin ore, thereby avoiding a substantial share of the energy burden of primary mining and processing. The magnitude of the saving is clearest for metals such as aluminum, where recycling uses on the order of 95% less energy than primary production,[63] and remains material for scrap-based steel—relevant because the majority (83%) of nickel produced in Indonesia is still used in stainless steel,[64] which is among the most recycled materials in the world.[65]

2.4 Social Co-Benefits

Implementing circular economy practices in mineral value chains can support a just transition by generating localized employment and improving community health outcomes. The International Labour Organization (ILO) estimates that circular activity could create on the order of 7–8 million additional jobs globally in areas such as recycling, repair, and remanufacturing, with most waste management and recycling jobs already located in the Global South.[66] This is especially relevant in Indonesia, where the nickel industry has created a very large workforce: the Indonesia Morowali Industrial Park (IMIP) alone employs on the order of 80,000–100,000 workers,[67] and circular activities such as battery collection, refurbishment, recycling, and tailings and slag reprocessing represent an opportunity to broaden nickel sector employment beyond primary extraction and processing. Indonesia's national circular economy modeling projects 4.4 million cumulative net jobs between 2021 and 2030, but covers only food and beverage, textiles, construction, wholesale and retail trade, and electrical and electronic equipment.[68] No comparable estimate exists for mining and metals, and the same modeling finds that circular transitions displace upstream jobs while creating downstream ones, prompting its call for skills policy to fill that gap. (Section 3.3.3).

Displacement is not the only employment risk. Nickel jobs are concentrated in a small number of industrial parks,[69] so if nickel demand falls, the loss lands on those workforces and host communities rather than being spread across the economy. The diversification case (Section 2.1) therefore has a social dimension: circular activities such as battery collection, refurbishment, and slag and tailings reprocessing widen the range of jobs available in these communities without depending on rising primary output.

Circular models also offer an opportunity to formalize informal labor.[70] An estimated 15–20 million people worldwide work as informal waste pickers,[71] and structured collection and recovery systems can bring some of this workforce into safer, more secure livelihoods, provided schemes are explicitly designed for inclusion rather than displacement. This is directly relevant to Indonesia, where end-of-life batteries and electronics are largely handled through informal value chains (Section 3.2.2).

Crucially, the social case for nickel circularity also runs through worker and community safety: Indonesia's nickel sector recorded dozens of fatalities and numerous serious accidents over recent years, and waste-related failures, including tailings landslides and waste pool explosions, are among the hazards. Circular practices that reduce stored waste volumes and improve handling can improve health and safety.[72]

As with the other dimensions of co-benefits, these are potential social co- benefits, realized only under appropriate policy design, enforcement, and—critically for the social dimension—attention to job quality and the inclusion of affected workers and communities.[73]

3. Integrating Circular Economy into Nickel Value Chains in Indonesia

The success of each circular economy intervention suitable to Indonesia's nickel value chain—recovering nickel from tailings and slag, reprocessing mine waste, building battery collection and recycling systems, and shifting toward servitization—depends on specific conditions being in place. The technology must exist and be accessible, the law must require or reward the practice, and the economics must work at the firm level, including the availability of capital to fund it, the infrastructure and logistic requisites, and the skills and labor capabilities. All need to be present in order for a circular economy intervention to deliver its potential co-benefits.

We group these into three enabling conditions, analyzed in the following sections: technical and technological (Section 3.1); policy, legal, regulatory and governance (Section 3.2); and economic and financial (Section 3.3). Each is necessary, and a deficit in any one can block an intervention that is otherwise sound; weak recovery technology, an absent regulatory mandate, an unviable cost structure, or a financing gap will each stop a circular practice from being adopted. Therefore, the recommendations that follow each section should be understood and analyzed as an integrated package, rather than as a menu of isolated interventions, since each contributes to creating the enabling environment for the others.

3.1 Technical and Technological Enabling Conditions

3.1.1 Overview of Best Practices in Circularity Technology

A technical enabling environment for circularity in critical minerals value chains rests on four conditions:

1. The maturity and readiness level of the technologies under the conditions in which they will operate
2. Characterization data on the materials to which those technologies are applied
3. Testing methods, standards, and laboratory capacity that make such data actionable
4. Domestic applied research capacity to adapt technology imported through technology transfer to local conditions.

This section addresses what is technically possible, and on what evidence, starting with applied research and adaptation capacity, because that is what allows the other three to be built domestically.[74]

Applied research and adaptation capacity is usually anchored in a dedicated institution that has government participation or support. National research institutions carry out the applied research that adapts proven technology to domestic ore bodies, waste streams, and operating conditions. A common approach is to establish a **national research institution** to focus on critical minerals, such as Brazil's Center for Mining Technology (CETEM) and South Africa's Council for Scientific and Industrial Research (CSIR).[75] Such institutions can rally multiple stakeholders around a common goal. For example, CETEM partnered with Brazil's leading mining association to produce a comprehensive report identifying "technological innovation, circularity and skill development" opportunities for iron, rare earths, lithium, and nickel, charting a path forward in this multistakeholder effort.[76]

Such initiatives do not necessarily require grounding in the public sector. **Domestic coalitions** of private sector and non-governmental organizations (NGOs) help to mobilize funding and boost reputational value for mining companies involved. For example, Brazil's Essential Minerals Coalition brought together 25 companies and coalitions to develop a collaborative approach to decarbonize the critical minerals sector, which stressed "technology and R&D" as a key enabling factor for circularity, and served as a valuable tool for regulators.[77]

Participation in **international partnerships and collaborations** is key to an enabling environment for circular technology, as parallel mineral contexts are ripe for technology transfer. Another example is Mexico's Sonora Plan, involving a "Train the Trainer" exchange in which Australian mining experts train university faculty and mining professionals to facilitate capacity building across Mexico.[78]

There are several international coalitions that also serve this purpose. The United Nations Industrial Development Organization (UNIDO), for example, hosts the Accelerate-to-Demonstrate (A2D) Facility, which provides grant funding for demonstration projects that accelerate the commercialization of clean energy technologies, including circularity in critical minerals value chains, in countries eligible for official development assistance, directly contributing to the country's enabling environment.[79] Similarly, the World Bank's Resilient and Inclusive Supply Chain Enhancement (RISE) Partnership looks to "create an enabling business climate" by providing technical assistance and facilitating investment in technology products in low- and middle-income countries.[80]

With the proper enabling environment and knowledge transfer, the various technologies and practices for process and product circularity in nickel value chains discussed as follows, many of which nearing cost-competitiveness globally,[81] serve as a menu of technological options that could be assessed for implementation in nickel mines, industrial parks, and further downstream in Indonesia. That menu is set out below against the first condition, maturity. Each technology is described together with the throughput, climate, or ore type conditions under which it has been demonstrated.

A. Process Circularity

Advanced geometallurgy—an umbrella term for the careful valorization of the ore and its surroundings—is situated near the high-value end of the 9R framework explained in Section 1, because it entirely rethinks the concept of extraction. Traditional extraction targets a single metal in a deposit and discards the rest of its surroundings, while advanced geometallurgy uses pre-extraction mapping to not only select deposits with less "waste," but also to assess waste rock for valuable properties and potential for repurposing.[82] Advanced geometallurgy advances the second condition of a technical enabling environment by converting characterization data about a deposit and its surroundings into decisions about what to extract and what to leave in place.

Bulk ore sorting applies this same strategy to the post-extraction phase, taking 10- to 200-pound "pods" of ore once extracted and evaluating their value for processing.[83] Sorting before shipping makes processing less wasteful because more valuable resources arrive at the industrial park. The circularity of an industrial park often depends less on improving disposal services, but rather making sure less "waste" is being disposed of there by implementing circularity upstream.

The most common method of storing tailings—the upstream dam—is prone to failure, especially in places with high seismic activity and rainfall,[84] as is the case in many mining areas in Indonesia. A solution to this issue is **filtered tailings** technology, which lowers the water content in the tailings and decreases risk of collapse. Considered Best Available Technology (BAT) for tailings storage, filtered tailings' circular value comes from increased water reuse and its potential for repurposing tailings for construction or fertilizer.[85] The water filtered out of the tailings can be reused, and the transition away from use of a standing body of water to store tailings eliminates loss from evaporation.[86] The optimal circular economy solution is to reduce the demand for mines and mineral processing altogether, since even the BAT for tailings storage harbors high risk.[87] Reducing that demand is what advanced geometallurgy and bulk ore sorting address, by identifying low-value material before it is extracted or before it is shipped for processing, so it is never transported, treated, or stored.

Re-mining works differently by reducing new extraction without reducing processing, and sits at the recovery end of the 9R framework. Many case studies exist for **re-mining tailings** for critical minerals, which reduces strain on the land and existing storage facilities.[88] Caveats include a lack of agreed-upon best practices, a lack of testing on nickel (most cases included copper, gold, and zinc), and a still-present risk for dam failure as a result of re-mining.[89]

Technology for **nickel slag reuse** has numerous applications, including for construction,[90] road aggregate,[91] and soil stabilization.[92] Nickel slag is primarily known for its ability to increase the durability and compressive strength of materials when blended.[93] The cement manufacturing industry produces 8% of the world's carbon dioxide (CO_2) emissions,[94] making nickel slag an ideal replacement: a blend of 40% ferronickel slag in cement-based materials reduces energy consumption by 31.7% and CO_2 emissions by 35.82%.[95] Beyond its use in stabilization and construction, nickel slag has applications as a partial replacement for topsoil and soil enrichment, providing a direct solution to the soil degradation caused by mine sites.[96] Realizing these applications depends on the third condition for enabling circularity from a technical perspective: slag has to be consistent enough for a buyer to rely on, so standards, and an agreed way to test them, are needed.

B. Product Circularity

Lithium-ion batteries in the EV market have a lifespan of 3–10 years, and around 1.2 million EV batteries could reach the end of their lives in 2030, rising to 14 million in 2040 globally.[97] The batteries are deemed "depleted" for use in EVs when they are lower than 80% capacity, leaving plenty of life to be **reused** as energy storage for a solar or wind farm (Figure 2). Only after the second life is completed should the end-of-life chemical recovery of nickel be employed.[98]

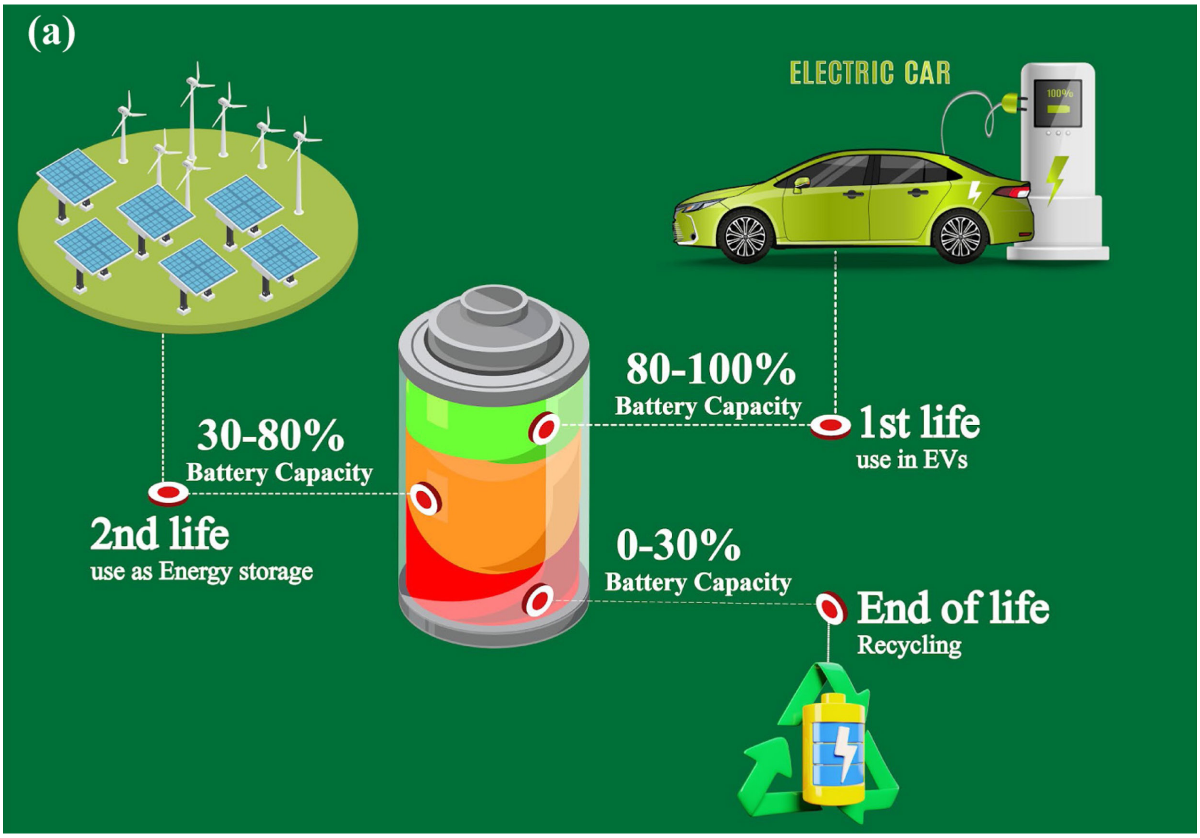

Figure 2. Lithium-ion batteries can have multiple "lives" before being recycled
Source: Rezaei (2025).[99]

Battery recycling has been innovated greatly since the 2010s, with early leaders like Umicore looking to capitalize on the rise in EV demand. Notably, Umicore utilized the energy present in retired batteries to help power their recycling process, giving them a kind of "third life."[100] Modern recycling companies break down batteries step by step through heating and shredding, selling off the steel casings, and reusing the energy lost. A powder mixture of lithium, nickel, cobalt, and copper remains, and is soon broken down chemically and separated into distinct metals.[101] Even before this process, leading recyclers identify reuse opportunities in their own operations. Industry leader Redwood Materials created an energy storage system (ESS) network—Redwood Energy—to use any batteries deemed still usable for a second life.[102]

Servitization as a way to promote battery reusability is gaining momentum. Direct current (DC) fast charging is popular to reduce charge times to 15–20 minutes, but the practice causes increased battery degradation when compared to slow charging.[103] Chinese battery manufacturers Nio and CATL are pioneering a "battery swap" scheme allowing EV owners to swap depleted batteries for new ones at stations across the country.[104] Not only does this avoid circularity-damaging practices like DC fast charging, it also incentivizes manufacturers to manufacture longer-lasting products since they retain ownership of the battery.

3.1.2 State of Play of Circularity Technology in Indonesia

Indonesia's position differs sharply across the four conditions for an enabling technological environment. Mature technology is present and expanding quickly in process circularity, while lagging in product circularity; characterization data, test methods, and domestic adaptation capacity are not keeping pace. The state of play below should be read against that asymmetry.

One of the most important developments for Indonesia's nickel value chains, with circular implications, is its rapid increase in HPAL facilities. Starting with the massive Chinese investment into IMIP in 2015, Indonesia has built 7 HPAL facilities since 2021, with 14 more either permitted or under construction (and 12 additional facilities in the proposal stage).[105] The growth in HPAL has driven increases in processing and refining capacity, expected to grow from 2.56 million tons of nickel in 2024 to about 3.07 million tons in 2026.[106] Considering all current, permitted, and planned facilities operating, an estimated 275 million tons of tailings would be produced.[107]

HPAL's rise in relation to traditional rotary kiln electric furnace (RKEF) operations drives both process and product circularity. Smelters require high-grade (saprolite) nickel ore to convert into ferronickel, a key component in stainless steel. HPAL, on the other hand, more efficiently turns low-grade nickel ore (limonite) into a more flexible product with multiple applications.[108] On the process side, this decreases waste by creating economic value from low-grade ore previously discarded as worthless. As for product circularity, HPAL is essential for turning nickel ore into battery-grade material, unlocking an entirely new market for reuse and recovery.[109]

A. Process Circularity

HPAL's ability to utilize low-grade nickel ore bodes well for otherwise gloomy trends in the mining industry—global mined nickel ore grades decreased by nearly 40% from 2001 to 2020, currently around 0.94%, while limonite ores range from 0.8 to 1.5%.[110] In other words, limonite ore is comparatively richer and resists the ore grade decline issue that plagues other critical minerals value chains, including hard-rock nickel. In general, smelted nickel has about twice the waste-to-metal ratio as HPAL.

However, though it processes nickel more efficiently than RKEF, HPAL produces a different *type* of waste—tailings—which are more high-risk to store than waste rock. High rates of precipitation and seismic behavior combined with weak soil and steep topography makes Indonesia prone to tailings failures.[111] Indeed, fatal landslides are frequently reported,[112] framing the looming number of 275 million tons of tailings as a major threat. On top of this risk, a recent report shows that select facilities in IMIP are "expected to process and store more waste than tailings facilities with comparable rainfall elsewhere in the world."[113]

HPAL technology in Indonesia is novel for two reasons: the speed at which it is being developed, and its use of filtered tailings in all projects to date. The 11 preceding HPAL nickel operations worldwide took place between 1959 and 2015, whereas Indonesia's "boom" of HPAL projects began in 2021.[114]

Although more common for the stainless steel value chain, nickel smelting is also prevalent in Indonesian industrial parks. As described above, its waste—slag—has circular applications that Indonesian mining companies are already exploiting. PT Vale's ECOTERAKO program substitutes slag for stone in road construction, reportedly reducing slag deposits by over 3 million tons in 2022.[115] Additionally, nickel producer Trimegah Bangun Persada (TBP) developed technology to turn slag into bricks, using it to recycle 643,234 metric tons of slag in 2023.[116] The company has mostly used the bricks for internal operations and housing on Obi Island. The common enabler across these cases was Government Regulation No. 22 of 2021, which lists nickel slag as registered non-B3 (non-hazardous and non-toxic) waste under code N102.[117]

The enabling effect of that reclassification is narrower in practice than it appears because reclassification alone does not permit transfer. Reuse remains confined by permitting to the operator's own concession. PT Vale Indonesia reports using all of its slag, but only within its own mining area, being permitted neither to sell it nor to transfer it to surrounding communities, so reuse continues only for as long as the company's own construction demand does.[118] Another producer reports holding a specific permit for reuse of slag as a building material, though does not report holding a permit that extends to transfer or sale beyond their operations.[119] Slag valorization is therefore revenue-positive within a firm but not yet tradable between them, which is the difference between waste avoidance and a secondary materials market.

Finally, PT Vale Indonesia is experimenting with a form of advanced geometallurgy called Electrical Resistivity Tomography (ERT). ERT compares relative resistivity among rock layers, providing a non-invasive method to determine the characteristics of laterite nickel layers, optimizing the process to produce less waste.[120] Explanation of its use is confined to scientific papers, however, with no mention of applications directly related to waste, such as ERT's potential to monitor tailings dam failure risk or even tailings valorization, representing an opportunity yet to be assessed by the industry in Indonesia.[121] ERT sits at the intersection of the second and third conditions: it is a characterization method, and extending it from ore bodies to waste would supply the residue data that circularity obligations already presuppose.

B. Product Circularity

Product circularity in the nickel battery value chain is still relatively new, as the emphasis has been on further upstream practices such as HPAL in the past decade. However, there are a few burgeoning projects that are setting the stage for circular operations in battery reuse and recycling. Servitization seems to be a low priority.

The Korean Green New Deal Trust Fund (KGNDTF) and the Global Green Growth Institute (GGGI) launched the Electric Vehicle Battery Recycling and Circular Electronics Management Project in February 2026.[122] The project looks to translate plans such as the BAPPENAS RAN-ES into action, with one core objective being an EV battery collection system and recycling facility pilot.

A project proposal that arose from partnership with the Republic of Korea, titled "Sustainable Mass Electric Transportation to Support Green Smart City in West Java," reflects the intention to utilize battery circularity.[123] Considering the government's goal for full electrification of urban mass transit by 2045, this project looks to establish an electric bus rapid transit (BRT) corridor in the region, complete with charging stations on a microgrid.[124] The charging station will be solar powered, utilizing used battery energy storage systems (BESS). Although the project makes no direct reference to circularity, its proposed reuse of batteries is in line with global best practices. The project has not released any public updates since its proposed 2024 start date, raising questions about its completion date of 2027.

In 2025, the Chinese battery manufacturer CATL broke ground on a "Battery Integration Project" aiming to centralize battery mineral value chains in Indonesia.[125] This includes circularity and promises capacity to process 20,000 tons of recycled batteries in the FHT Industrial Park once fully operational in 2031.[126]

The last notable project on the horizon is a March 2026 memorandum of understanding (MOU) between Hyundai and Zhejiang Huayou Recycling Technology to build a recycling facility in Indonesia.[127] Considering the latter company is an affiliate of Huayou Cobalt Battery, it is likely the battery plant will have a focus on nickel-cobalt chemistries rather than LFP.

All of these projects are in the very early stages, reflecting the up-and-coming nature of the product circularity movement in Indonesia, powered by both South Korean and Chinese partnerships.

3.1.3 Gaps, Challenges, and Opportunities of Circularity Technology in Indonesia

A. Process Circularity

The biggest technological challenge facing circularity in Indonesia's nickel industry is the lack of options for tailings storage tied directly to the rapid deployment of HPAL facilities in recent years. The situation is sufficiently pressing that leading civil society organizations are calling for a moratorium on the development and permitting of new facilities until the safety issues are resolved.[128]

Although filtered tailings are indeed considered BAT for tailings management,[129] their use in Indonesia has limitations. Some constraints are environmental and contextual: the precipitation, seismicity, soil, and topography conditions (Section 3.1.2) fall outside the envelope in which filtered tailings have been demonstrated, which is a gap in the domestic applied research to adapt the technology acquired through technology transfer.[130] Combined with the factor of local populations living downstream, this caused the employees of the first HPAL project in Indonesia to remark, "tailings application for Halmahera tropical region is less suitable…the cost of construction and water control will be very high and is not feasible for the project economically."[131]

The technical issue with filtered tailings in Indonesia is the risk of liquefaction. Whereas the nickname "dry stack" tailings implies zero moisture before storage, the reality is more complex: HPAL tailings require higher water content to neutralize the effect of the acid leaching, making it more difficult to reach optimum water content for the practice compared to conventional filtered tailings.[132] Even once the optimum water content is reached, it can be undone by the heavy rainfall of the region. While not impossible, the precarious situation of filtered HPAL tailings in Indonesia requires stringent regulation and monitoring to be deemed safe. Figure 3 shows the current technological limit (bounded by average rainfall) on the height of filtered tailings dams, demonstrating the risk of dams like PT HPL on Obi Island—the only filtered tailings storage facility with a known maximum height.[133] Missing on the graph is a comparison of throughput; whereas Greens Creek is well over the technological limit, its throughput is 1,500 metric tons per day, compared to PT HPL's 20,537 metric tons per day. As discussed in Section 3.2, Indonesia lacks regulations or standards specific to filtered tailings storage facilities, making this a major challenge for HPAL expansion and, thus, a more circular nickel value chain.[134]

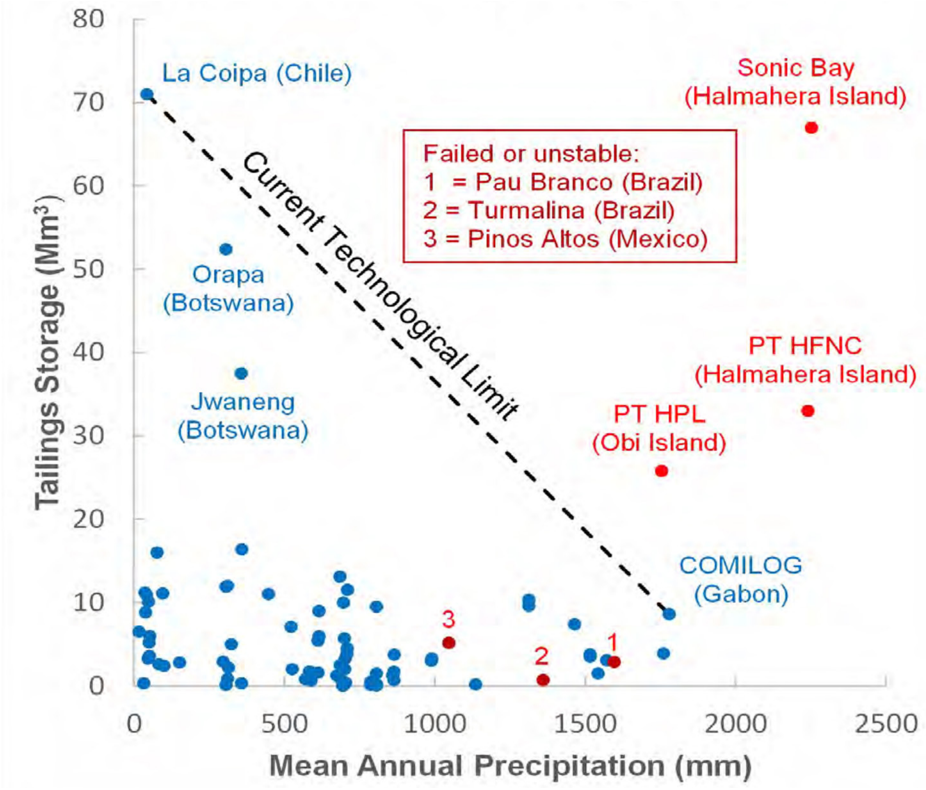

Figure 3. Current filtered tailings storage facilities

Source: Emerman et al. (2026).[135]

Indonesia has enough of a challenge storing HPAL tailings safely, making their valorization equally difficult. Even though current regulation requires companies to report information on tailings management and reprocessing, a lack of information on the components of tailings deposits in Indonesia, in practice, makes even the first steps towards re-mining very challenging, not to mention the increased risk of failure caused by any invasive procedure carried out in tailings facilities.[136] This is a gap in the second condition for a technical enabling environment for circularity: without a technical characterization capability, an obligation to report on residues is impossible to fulfill. Beyond re-mining, low-value products like road aggregate and fertilizer are other opportunities for valorizing tailings, but they are limited to local markets to minimize shipping costs.[137]

Nickel slag reuse faces its own challenges. Expensive processing methods, variable quality, and lack of steady supply of inputs make it difficult for small- to medium-sized companies to justify investment. Similar to tailings re-mining, the lack of sufficient data and standardized processes harms the case for use of slag in materials like cement due to the variable composition of byproducts.[138] Geographic isolation of smelters is also a major barrier, as transportation costs of heavy slag is high and nearby land availability is low. Slag reuse has more uptake than tailings reuse, but current usage is described as "passive," and requires systematic integration into industrial practices to prove its worth and shift public perception away from slag being merely hazardous waste.[139]

A major opportunity for process circularity in Indonesia is establishing composition ranges for Indonesian slag and a repeatable procedure for testing a blend against them. The value is already documented. Nickel slag raises the durability and compressive strength of blended materials (Section 3.1.1). Specification is what converts that demonstrated property into a material a buyer can design around. Some of that work has been done domestically testing chromium and cadmium leaching from solidified nickel slag used as fine aggregate in concrete flooring, found leachability below the applicable Indonesian threshold, and identified an optimum dosage meeting construction specification.[140] The result demonstrates that the characterization and specification work the third condition requires is within reach of existing Indonesian research capacity, on Indonesian material, and does not depend on imported expertise.

Indonesia is already utilizing the practice of filtered tailings in its HPAL operations, but the so-called BAT requires extra caution in the tropical climate context. The only proposed technical solution for wet weather filtered tailings facilities is a pre-planned, non-structural zone for dumping tailings during rainstorms, which lowers the risk of the entire structure failing.[141] This is already standard practice for filtered tailings facilities worldwide, undoubtedly designed for more sporadic downfalls, but incorporating this as a baseline safety measure would go a long way to justify the continued use of the filtered tailings technology in Indonesia. The technology itself is sound, but the rushed manner in which it has proliferated in the country has caused numerous fatal disasters.

Safe tailings management is a big enough circularity opportunity in itself, even if the reuse of tailings for extractive and non-extractive applications is not yet ready. As detailed in Section 3.1.2, HPAL is not only a less waste-intensive method of nickel extraction, but also values low-grade ore as more than just waste rock. However, if the challenges (Section 3.1.3) are not addressed, the risky and fast-growing nature of the industry will threaten its longevity. Technically derisking tailings storage is therefore the most significant near-term opportunity for process circularity in Indonesia's nickel sector.

A final forward-looking opportunity for process circularity is to use ERT for safety and waste characterization. Already used in Indonesia for ore deposit characterization, its low-impact analytical capacity is also ideal for the high-risk nature of Indonesia's tailings facilities. The technology is still in its early stages, but has already been used to identify contaminant release from a tailings pond in Honduras.[142] Additional studies tout its potential to detect erosion, dangerous water levels, and serve as an early-warning system for catastrophic failure.[143] ERT can also serve to estimate the remaining mineralization in both tailings and slag.[144] The authors are unaware of any application of ERT to the waste context in Indonesia, but its present use by companies such as PT Vale Indonesia show that it would be possible and can be a candidate method for satisfying legal residue characterization obligations.[145]

B. Product Circularity

On the product circularity side, the biggest challenge is on the third condition for a technological enabling environment for circularity: the methods by which recovered material is graded and shown to be fit for its next use. A retired pack has to be graded before it can enter a second life. Grading is a technical measurement problem. Retired EV packs typically retain 70–80% of their original capacity, but state of health is specific to the individual pack, because every battery has been exposed to a different duty cycle, so remaining capacity has to be measured on the unit rather than inferred from its model or age.[146] Grading in turn depends on an agreed testing procedure. ANSI/CAN/UL 1974, the Standard for Evaluation for Repurposing Batteries,[147] is the most developed procedure internationally. It is a testing protocol that specifies the technical procedure to grade a pack. Indonesia has not built the technical capacity to establish a grading protocol for retired packs.

Additionally, two properties of the method itself constrain how far grading can scale. Test burden rises with how far a pack is taken apart, because every unit separated has to be graded individually: a cost model of a UL 1974-certified facility puts pack-level processing at roughly a third the cost of module-level, which is why cell-level repurposing is rare in practice.[148] And state of health cannot be established without the pack's original specification, so the measurement depends on data the measurer does not hold, and minor differences between model years can require the grading procedure to be re-established, making mixed feedstock slower and costlier to process than a uniform stream.[149]

Moreover, when dismantling the battery, pack architectures differ widely between manufacturers in cell format, structure, and joining method, which keeps disassembly manual and limits automation, and cathode chemistry is frequently unlabeled or inadequately documented on the casing, so recyclers have to test each pack to find out what is in it before they can sort it, creating a technical challenge.[150]

Battery recycling is divided into two stages. Pre-treatment involves discharge, dismantling, crushing, and sorting, which yields black powder, a mixed intermediate containing lithium, nickel, and other metals. Post-treatment refers to the hydrometallurgical or pyrometallurgical extraction that converts the intermediate into battery-grade compounds. Indonesia has a clear opportunity to leverage the first stage. A model that stops at black powder recovers around 74% of input weight as black powder and a further 23% as other recoverable material, leaving roughly 3% as waste. Carrying the process through to final metal extraction increases the value of the output but reduces total recovery to about 83% and increases waste to around 17%.[151]

Indonesia's position on feedstock is also favorable, which is not the case in most markets building recovery capacity. The pack heterogeneity that constrains recyclers elsewhere (Section 3.1.3) is less acute here: more than 90% of EVs sold in the country in 2025 used LFP chemistry, supplied by a small number of manufacturers,[152] so the domestic stock retiring over the next decade is likely to be comparatively uniform in both chemistry and pack architecture. Homogeneous feedstock is the condition under which automated dismantling and consistent grading become viable. This suggests that the chemistry shift from nickel-bearing cathode chemistries to LFP batteries identified as a demand risk (Section 2.1) may, at the recovery end, be an operational advantage. The advantage favors a recovery industry built around lithium and iron phosphate rather than nickel, which is consistent with the diversification case (Section 2.1.)

Accordingly, Indonesia has a sequenced opportunity. Beginning with storage and pre-treatment, Indonesia could build collection systems, safety practices, and supply chain reliability at lower cost and lower environmental burden, while selling black powder into an established global market. A division of roles where the state operates storage and pre-treatment hubs and the private sector leads metal extraction and material production is a starting point.[153] The known weakness of a pre-treatment-only model is that it depends on market access for its intermediate output, which is where regional recognition of secondary materials becomes a precondition (Sections 3.2.1 and 3.3). This staging also matches the structure the recovery economics favor at regional scale, with distributed pre-treatment feeding concentrated processing capacity (Section 3.3). Post-treatment capacity, remanufacturing, and the associated R&D can follow once the regulatory environment for EV battery circularity is more developed, accepting the higher waste burden that comes with them.

3.1.4 Recommendations for the Technical and Technological Enabling Conditions of Circularity in Indonesia's Nickel Value Chains

The technical constraint on circularity in Indonesia is not the availability of technology but the conditions for deploying it, and the recommendations below follow the four conditions set out in Section 3.1.1. On maturity, filtered tailings storage needs design provisions matched to tropical rainfall before it is extended further. On characterization, residue composition data does not exist at the required standard for reprocessing or specification decisions. On methods and standards, there is no accepted test procedure for residues or repurposed batteries. On adaptation capacity, domestic applied research remains thin. Each recommendation names the condition it addresses and, where relevant, the regulatory or financing measure in Sections 3.2 and 3.3 on which it depends.

A. Process Circularity

- Build a national research capability for critical minerals by designating an institution to coordinate applied research on residue characterization, reprocessing, and slag and tailings valorization, building on examples such as Brazil's CETEM and South Africa's CSIR.

- Require structured knowledge transfer, as in Mexico's Sonora Plan, so domestic engineers can operate and adapt the technology. UNIDO's Accelerate-to-Demonstrate (A2D) Facility and the World Bank's RISE Partnership are available entry points.
- Define the rainfall, throughput, and moisture parameters within which filtered tailings can be operated safely in Indonesian conditions, including pre-planned non-structural placement zones for heavy rainfall. The technology is demonstrated elsewhere; the work is establishing where the envelope lies in Indonesia.
- Apply ERT, already used by Indonesian operators for laterite characterization, to tailings monitoring and residue characterization, where it can detect contaminant release, erosion, and dangerous water levels, and estimate remaining mineralization.
- Prioritize waste prevention over waste treatment by supporting advanced geometallurgy and bulk ore sorting so lower-value material is left in place rather than transported, processed, and stored. Industrial park circularity depends not only on improving disposal, but also on reducing what arrives to be disposed of.
- Characterize slag from operating smelters sufficiently to define composition ranges, and adopt a repeatable procedure for testing a blend against a construction product specification, which makes slag tradable between firms instead of only reusable within one.

B. Product Circularity

- Develop a technical repeatable procedure for assessing state of health at pack level, drawing on international protocols such as UL 1974, together with the laboratory capability to apply it.
- Stage battery recovery capacity. Begin with collection, storage, and pre-treatment to black powder, which recovers more of the input at lower capital and environmental cost, and treat post-treatment extraction and remanufacturing as a later phase contingent on regulatory maturity and market development.
- Determine whether storage and pre-treatment hubs are publicly operated with extraction led privately, and establish who carries responsibility for safety, traceability, and offtake at each stage.
- Secure market access for intermediate output. A pre-treatment model depends on selling black powder externally, which makes the classification and mutual recognition measures in Sections 3.2.1 and 3.2.2 a precondition for the sequence.

3.2 Policy, Legal, Regulatory, and Governance Enabling Conditions

3.2.1 Overview of Best Practices in Policy, Legal, Regulatory and Governance Circularity Frameworks

Introducing process and product circularity in Indonesia's nickel value chain depends significantly on the policy, legal, and regulatory frameworks relevant to both process circularity (Section 3.2.1(A)) and product circularity (Section 3.2.1(B)), as well as the institutional capacity and governance conditions (Section 3.2.1(C)) that create an enabling environment for circular economy principles and practices. Together, these frameworks and conditions can harmonize standards, reduce risk for implementing parties, align incentives, and help coordinate across the full life cycle of materials and products. These enabling conditions consist of national, subnational, and regional laws, policies, institutions, and market-shaping measures across the full life cycle of nickel value chains.

National circular economy roadmaps are a foundational starting point for integrating circular economy approaches into a country's policy landscape, as they provide shared definitions, targets, and implementation pathways.[154] National circular economy roadmaps should explicitly cover both process and product circularity policies relevant to the full life cycle of mineral chains, promote producer ownership as appropriate, and harmonize all laws related to a particular sector. Further, grounding national roadmaps in the 9R framework can help prioritize higher-value strategies in high-impact sectors over lower-value recycling-only approaches.

Roadmaps, however, are only effective when integrated into industrial policy, climate and decarbonization strategies, and mineral value chain planning, and when supported by implementation guidance that can be operationalized across various levels of governance. The next few sections outline specific policies through which such implementation can be carried out.

A. Process Circularity

Policy frameworks for process circularity are necessary to support reduced resource use and waste, and increased recovery of value at both mine sites and industrial parks where nickel is processed. As a matter of best practice, policy frameworks for process circularity should go beyond waste management and aim to reduce losses across the full life cycle (including through optimization of the extraction and operational process to minimize energy, water, land, and material waste), and support the recirculation of by-products across industrial systems to promote symbiosis. This requires a combination of policy measures such as increased regulatory certainty (for example, on waste versus by-product classifications), technical standards for waste management and processing, and incentives for evidence-based recovery and reuse pathways across industries and sectors.

Classification of waste, by-products, and secondary raw materials

Laws and regulations should distinguish mining waste, by-products, and secondary raw materials to ensure that valuable by-products are not disposed of where reuse or sale for secondary use in other industries is still technically feasible.[155] For example, "end of waste" criteria can provide a reclassification pathway for materials demonstrated to be non-hazardous (such as nickel slag) in order to remove administrative barriers to secondary use, as seen in Queensland, Australia.[156] This reclassification ensures that once a material is proven safe and meets technical standards, it legally ceases to be waste, allowing for its sale into other industries for secondary use. All reclassifications should be verified by independent third-party testing to prevent "product" status from being used as a loophole to bypass long-term environmental liability.[157]

Tailings management

The Global Industry Standard on Tailings Management (GISTM) provides a starting point for designing policies that support responsible tailings management.[158] Building on this baseline, the Safety First Guidelines for Responsible Mine Tailings Management highlight opportunities to further strengthen tailings management standards, particularly by emphasizing precautionary, consequence-based design approaches where the severity of potential impacts, especially loss of life, drives engineering decisions.[159]

Specific policy levers include mandating the use of best available technologies for tailings management;[160] requiring design and engineering to be responsive to the impact and severity of any failure, rather than its probability;[161] setting specific technical criteria for tailings facilities governing design, operation, maintenance, and closure;[162] requiring that corporate boards of directors bear primary legal and financial accountability for tailings safety, including by ensuring at least one board member holds relevant technical expertise in tailings failure risk;[163] and mandating an independent evaluation of all aspects of design, construction, operation, maintenance, and closure by an independent tailings review board.[164]

Relevant to the specific conditions of HPAL operations, which generate high volumes of toxic waste, the safest tailings facility is the one that is not built.[165] The volume of tailings generated therefore is not simply an engineering variable but also a policy question, and one that governments should consider in light of broader economic, environmental, and developmental goals when determining the scale and pace of nickel production it wishes to support.

Tailings reprocessing

Once tailings management efforts are established in line with best practice, governments should also explore the possibility of tailings reprocessing. Any policy effort to advance nickel reprocessing should begin with initiatives to gather information on raw material content in tailings to help evaluate secondary use options, as well as technical and economic feasibility of reprocessing. Several jurisdictions have implemented relevant initiatives, ranging from voluntary databases, such as Australia's Atlas of Re-mining Potential[166] and Finland's Geological Survey mine waste inventories,[167] to mandatory reporting requirements, such as those under the EU Critical Raw Materials Act, which requires operators to submit assessments of the quantities and recoverability of critical raw materials in extractive waste.[168]

Beyond data, enabling reprocessing requires addressing the legal barriers to working with tailings. As discussed in Section 3.1, the technology for nickel tailings reprocessing is still emerging, and its technical, economic, and social feasibility is not yet established. Assuming technological readiness is achieved and feasibility considerations are satisfied, a key policy priority should be to address any legal barriers to working with tailings as part of waste classification frameworks. Policy instruments similar to Ontario's Mineral Recovery Permit[169] could be tools to authorize reprocessing as a distinct activity and provide a risk-based pathway for re-mining.

Slag valorization and industrial symbiosis

Realizing the value of nickel slag and other by-products that have potential secondary uses requires policy frameworks that actively facilitate industrial symbiosis rather than simply permitting it. Beyond enabling secondary use through waste reclassification pathways, as discussed above, relevant policy instruments could include co-location incentives to position processing facilities near potential off-takers such as cement producers or construction material manufacturers.[170] Where industrial symbiosis is not technically or economically feasible, landfilling of potential recoverable materials should be a last resort, subject to the restrictions discussed below.

Landfilling restrictions

Landfilling of mine processing residues that retain recoverable value should be discouraged or prohibited where technically or economically feasible alternatives exist. Policy instruments include restrictions on landfilling specific categories of recoverable material, landfill levies that internalize the environmental cost of disposal and create price signals in favor of recovery and reuse, and requirements that operators demonstrate that no technically feasible recovery alternative exists before landfill disposal is approved.[171]

Post-mining land use, rehabilitation, and reclamation

Governments should require that land reclamation plans be developed during the early planning stages of any mining operation, rather than at closure,[172] and that such plans include consideration of beneficial post-mining land uses appropriate to local ecological, social, and economic conditions.[173] Policy mechanisms include providing technical guidance on reclamation standards and methods; setting clear, measurable thresholds for compliance that define what constitutes successful reclamation;[174] developing frameworks to identify and evaluate sustainable post-mining land uses, which may include ecological restoration, agriculture, renewable energy development, or community uses;[175] and establishing reclamation guarantee funds or bonds that ensure financial resources are available for rehabilitation regardless of changes in ownership or corporate solvency.[176]

Water management

Water reuse represents one of the most significant opportunities for process circularity in nickel production. Industry best practice, as reflected in the ICMM Water Stewardship Maturity Framework, identifies maximizing water recycling and reuse as a core element of responsible water management.[177] Governments can translate this best practice into binding requirements by requiring operators to submit water management plans as permit conditions;[178] mandating public reporting of water consumption and recycled water volumes;[179] and restricting freshwater withdrawal allocations in water-stressed areas, as Chile has done through its reformed Water Code,[180] to strengthen market incentives for reuse.[181]

Energy sources and efficiency

Energy circularity is the dimension of process circularity most exposed to overlap with the mining–energy–industry feedback loop discussed in the companion piece,[182] so this section refers to the circularity-specific levers. Within that boundary, best practice for energy circularity in mineral processing has two strands:

- **Energy efficiency and recovery within the facility**: capturing and reusing waste heat (for example, the steam generated by HPAL), recovering energy embodied in process streams, and, on the product side, using the residual energy in end-of-life batteries to help power their own recycling, as established recyclers have done (Section 3.1).[183]
- **Coupling circular processing with renewable energy systems**: the energy savings from secondary production are only realized as emissions savings if the energy itself is low-carbon (Section 2.2). Policy levers include requiring energy management and waste heat recovery plans as permit conditions, mandating reporting of energy consumption and recovered energy, and ensuring that environmental-permitting procedures do not inadvertently penalize efficiency upgrades. The broader questions of decarbonizing power sources and grid integration in industrial parks are addressed in the feedback loop report.[184]

B. Product Circularity

Product circularity can be scaled through policy measures that ensure that products (in this case, batteries) retain value across multiple life cycles, enable safe and high-value recovery at the end of life, and build dependable markets for secondary use of products or materials. Legal and policy frameworks should go beyond reuse and recycling, and encompass tools such as design requirements, digital battery passports, extended producer responsibility (EPR), and producer ownership and servitization models.[185]

Waste classification, recycling, and recovery requirements

To ensure that valuable materials are recovered through qualified processes rather than disposed of or informally handled, regulations should require waste batteries to be collected and processed through approved pathways, including rules for safe handling, minimum recycling efficiency, and material recovery expectations for batteries.[186]

Extended producer responsibility (EPR)

EPR extends a producer's responsibility to the post-consumer stage of a product's life cycle. By shifting responsibility upstream (to the producer), EPR provides incentives for more environmentally sound product design.[187] EPR typically requires producers to organize and fund collection, safe transport, treatment, and end-of-life management of batteries they place on the market. EPR frameworks typically include take-back obligations, collection targets, financing requirements (often via a producer responsibility organization (PRO)), and compliance reporting.[188] They may also include eco-modulated fees, where producers pay higher or lower fees depending on battery design choices that affect safety, durability, repairability, and recyclability.[189]

In practice, however, international experience shows that EPR schemes have often functioned primarily as waste financing mechanisms and have shown limited success in influencing upstream product decisions.[190] For EPR to support product circularity, it must be structured to create meaningful incentives for durability, second-life use, and high-value recovery, rather than simply requiring financing of end-of-life disposal.

The design of the PRO regime determines whether it advances circularity or merely finances disposal. International experience across EPR governance models, whether built on multiple competing PROs, a single PRO, or a state-run body, indicates that all require active government involvement to enforce environmental standards, transparency, and a level playing field, and that EPR schemes to date have had limited effect on product design.[191] Without that oversight, a PRO becomes a mechanism for absorbing end-of-life costs rather than one that shifts producer decisions toward durability, reuse, and high-value recovery. Moreover, without the enabling environment to act on, meaning the collection networks and licensed capacity that recovery requires, a compliant scheme can meet its financing and reporting obligations while recovery rates stay flat, because an EPR obligation directs material toward licensed handlers; it does not create them.[192]

Moving towards producer ownership through leasing and servitization, including batteries-as-a-service (BaaS)

In light of the shortcomings of EPR schemes, product circularity frameworks should ideally go beyond traditional EPR and actively enable producer ownership models, including through leasing and servitization.[193] Servitization is a business model and regulatory option where users pay for the right to use a product, instead of purchasing it outright and owning it. In batteries-as-a-service (BaaS), ownership remains with the battery provider or manufacturer, who retains responsibility for maintenance, monitoring, replacement, refurbishment, recovery and repurposing for second-life use, and end-of-life recycling. This supports circularity by keeping batteries in a closed-loop system and improving return rates for reuse and recycling.

Unlike conventional EPR systems, which rely on creating post-consumer use collection and handling incentives, producer ownership models such as servitization structurally transform and align commercial incentives with enabling longer battery life, modular repair, safe upgrading, and high-value recovery. When producers retain ownership, durability and recoverability become core business interests.

Servitization can be implemented using various models, including metals-as-a-service (MaaS) (see Box 2)[194] and batteries-as-a-service. BaaS is emerging in some jurisdictions. China[195] has built the most developed policy framework for it; India[196] has advanced a partial one focused on two- and three-wheelers (Box 1). Governments can make models like BaaS commercially viable through a combination of approaches including top-level policy signaling, national standard setting for swap interoperability and safety, fiscal treatment that recognizes battery and vehicle as separately owned, public procurement, pilot programs, and investment incentives for swap and BaaS infrastructure.[197]

Box 1. Policy-Enabled BaaS in China and India

Two of the world's largest EV markets have made BaaS work at commercial scale, leveraging on policy instruments to enable this business model. Battery swapping and BaaS are distinct. Swapping is an operation, exchanging a depleted pack for a charged one. BaaS is an ownership model in which the provider keeps title to the battery. Each can exist without the other, and it is retained ownership, not swapping, that changes producer incentives. Both countries built swapping infrastructure, but what made BaaS possible was resolving the ownership question through a policy or legal instrument.

China

The top-level signal was made by the government in May 2020 when battery swapping stations were written into the Government Work Report as part of new infrastructure.[198] The Ministry of Finance then exempted battery-swap models from the RMB 300,000 vehicle price cap that otherwise limited purchase-subsidy eligibility, a fiscal carve-out that made premium swap-capable models eligible.[199] The Ministry of Industry and Information Technology issued the first national standard for the mode, GB/T 40032-2021, Safety Requirements of Battery Swap for Electric Vehicles, in force from November 2021 and developed jointly with battery suppliers and third-party operators, resolving the absence of any common technical reference.[200] In 2021 MIIT launched a pilot across eleven cities, eight for general application and three focused on heavy-duty trucks, targeting more than 100,000 swap-capable vehicles and more than 1,000 new stations.[201] Purchase tax treatment did the ownership work: where the vehicle and the battery are invoiced separately, the taxable price is the vehicle body alone, which is what allows a buyer to purchase a car without its battery and leaves title with the provider.[202]

The result is a functioning market. China had 555 swap stations in 2020 and 1,298 by the end of 2021.[203] NIO alone ended 2025 with 3,676 stations in China, opened its 4,000th in August 2026, and by that date had completed 100 million cumulative swaps since its first station opened.[204] Energy majors and battery makers followed. CATL entered the sector in 2022, launched its standardized Choco-Swap ecosystem in December 2024, and signed a partnership with Sinopec in April 2025 to combine its swap technology with Sinopec's national service-station network. It reached 1,020 stations within a year, deployed its 2,000th in June 2026, and targets more than 3,000 by the end of 2026 against a long-term goal of 30,000.[205]

India

India's approach targets the vehicle classes that dominate its market. NITI Aayog (India's National Institution for Transforming India) issued a draft Battery Swapping Policy in April 2022 covering electric two- and three-wheelers, proposing interoperability standards, subsidies de-linked from battery ownership, and resolution of the GST differential between standalone batteries and complete EVs.[206] The Ministry of Power's January 2025 guidelines then brought swapping stations into the national EV infrastructure framework, set technical and safety standards, and made a regulatory distinction between ownership of the battery and of the vehicle, while the Ministry of Road Transport and Highways permitted registration of battery-less EVs, giving legal status to vehicles sold without a battery.[207] Under the PM E-DRIVE scheme, swapping stations became eligible for infrastructure subsidies.[208]

What this means for Indonesia

The enabling instruments are conventional: a standard, a tax treatment, a registration rule, and a pilot. The binding constraint in both countries was legal recognition that battery and vehicle can be owned separately, which is strictly a policy decision independent of any technological consideration, and not yet implemented in Indonesia (Section 3.2.2). And India's targeting of small vehicle classes is the closer analogue for Indonesia, where motorcycles account for roughly four fifths of the vehicle fleet[209] and where swap economics are far more favorable than for passenger cars, since a two-wheeler station holds racks of small packs rather than a costly inventory of car batteries.

Circular product design requirements

Product design rules or standards can require batteries to be designed in ways that support longer product life and higher recovery. For nickel batteries, producers could be required to consider life-cycle emissions at the design stage, advancing designs that promote modular durability, material efficiency, safe and easy disassembly, replaceable components, and reduced use of hazardous materials.[210] These rules help prevent batteries from being treated as "sealed waste" and instead make them maintainable and recoverable.

Labeling and digital battery passports

Digital battery passports are standardized digital records linked to a battery pack that store information needed to keep the battery in use longer and recover materials end-of-life.[211] A battery passport can include information on battery chemistry, material composition (including nickel content), manufacturing data, safety information, state-of-health history, repair and disassembly instructions, and recycled content.[212] Battery passports improve traceability, support second-life decisions, and strengthen sorting and recycling outcomes. However, information gathered from digital battery passports does not by itself produce circularity. A passport requirement is satisfied by supplying data, and compliance with it is easy to verify, but whether the data changes anything depends on its accuracy, on whether it reaches actors who can act on it, and, more importantly, whether it is connected to regulatory requirements, economic incentives and the physical infrastructure needed to act on it.

Targets and requirements for secondary materials and secondary use

Technical and regulatory standards can set specific material recovery targets, collection rate targets, and minimum recycled content requirements with increasing levels of ambition.[213] Minimum recycled content requirements typically rely on traceability and verification to ensure credibility and create demand for domestic recycling and refining.

Standards for secondary use also encompass quality standards for secondary minerals and metals and by-products, and their reuse across industries.[214] In the case of batteries, standards could enable the reuse of EV batteries considered depleted for energy storage in wind or solar farms before end-of-life chemical recovery of nickel takes place (as discussed in Section 3.1.1). Policy frameworks should also include quality standards for recycling technologies.

Creating a market for secondary use and second-life applications of batteries

Product circularity frameworks can also actively create demand for secondary use of batteries. This can be done, for instance, by introducing public procurement requirements favoring second-life batteries in specific applications (such as grid storage projects), fiscal incentives for energy storage projects that incorporate second-life batteries, and mandated assessment of second-life suitability before recycling is authorized. The last of these addresses a tension that recycling-focused frameworks can create. Recycled content and recovery targets, including those in the EU Batteries Regulation, can make it more attractive to recycle a retired battery than to repurpose it, producing a mismatch between what life-cycle assessment supports and what policy rewards.[215] Frameworks should therefore prioritize the highest-value use across the full life cycle and treat repurposing and recycling as complementary, which requires battery health and life-cycle data adequate to determine when second-life use delivers more value than immediate recovery.[216] Absent such measures, repurposing remains under-incentivized relative to recycling and second-life business models stay dependent on project-level support.[217] These demand-side measures are also the precondition for the producer ownership models (MaaS and BaaS) discussed above, which depend on a functioning secondary-use market to be commercially viable.

Reporting and disclosure requirements

Policy measures should also include obligations for producers and recyclers to measure and report on batteries placed on the market, batteries collected, treatment routes, recycling and recovery rates, along with evidence of compliance with safety and environmental requirements.

C. Governance

Well-designed process and product circularity policies require governance conditions that make them operate: clear institutional mandates, coordination across agencies and levels of government, and monitoring, data, and enforcement capacity. As a matter of best practice, five governance elements are foundational.

Clear institutional mandates and capacity

Circularity in nickel value chains cuts across mining, environment, industry, energy, and spatial planning authorities. Best practice assigns explicit responsibilities for each circularity function—standards-setting, permitting, monitoring, and enforcement—so that no function falls between agencies, and ensures the responsible bodies have the technical capacity to discharge them.[218]

Intra-governmental and cross-sector coordination

Because materials move along a value chain that spans jurisdictions and ministries, circularity requires coordination mechanisms—shared definitions and targets (the role of a national roadmap), joint planning, and consistent operational rules at the subnational level—to prevent fragmentation and regulatory arbitrage.[219]

Monitoring, data, and transparency

Setting and tracking circularity targets requires data collection: material registries, tailings and waste inventories, stock-and-flow accounting, and producer reporting. Best practice mandates collection and public disclosure of facility-level data, environmental assessments, and compliance results, so that regulators, communities, and investors can independently verify that commitments are met.[220]

Enforcement and accountability

Rules require credible enforcement: inspection regimes, penalties for non-compliance, financial assurance that survives changes in corporate ownership, and accountability that reaches corporate decision-makers. Best-practice tailings governance, for example, places primary legal and financial accountability for safety on corporate boards and requires independent review (Section 3.2.1(A)).[221]

Regional integration and coordination

The governance instruments that determine whether secondary materials can move are substantially international, and three matter for nickel and battery value chains: classification, the treatment of transboundary movement, and the regional policy architecture.

Classification. A by-product or secondary raw material recognized in one jurisdiction but treated as waste in another cannot be traded without permitting and compliance costs that frequently exceed its value, so mutual recognition of end-of-waste criteria is what converts a domestic reclassification into market access. Common criteria also act as a safeguard against waste dumping, where each jurisdiction defines by-product status on its own terms, genuine waste can be relabeled and shipped to whoever inspects the least. Classification at the border is the precondition for either to work.

Where a material has no tariff code it cannot be distinguished from waste in customs processing, whatever criteria the parties have agreed; in Indonesia, used batteries currently have no dedicated classification, and the customs authority is reported to be examining the creation of one.[222]

Treatment of transboundary movement. All ten Association of Southeast Asian Nations (ASEAN) Member States are parties to the Basel Convention,[223] which since January 1, 2025 has subjected both hazardous and non-hazardous electrical and electronic waste and scrap to prior informed consent of the importing country.[224] Article 11 of the Convention permits Parties to enter into bilateral, multilateral, or regional agreements on the transboundary movement of hazardous and other wastes, with Parties or non-Parties, on the condition that such agreements do not derogate from the environmentally sound management the Convention requires and stipulate provisions not less environmentally sound than its own, taking particular account of the interests of developing countries.[225] This supplies the legal route to an ASEAN regional arrangement on prior consent or expedited clearance for verified secondary materials in nickel and battery value chains. The operational form such an arrangement would take has been set out as a regional "green lane" for movement of end-of-life batteries and black mass between approved facilities, resting on harmonized permitting, packaging, and labelling procedures, digital prior informed consent, trusted-operator frameworks, and common technical standards.[226]

Regional policy architecture. The first guiding principle of ASEAN's Framework for Circular Economy for the ASEAN Economic Community is the promotion of ASEAN integration and the development of regional value chains. Among its strategic priorities are the harmonization of standards and mutual recognition of circular products and services, and trade openness and facilitation for circular goods and services.[227] A second and more directly relevant instrument is the ASEAN Minerals Cooperation Action Plan 2026-2030 (AMCAP-IV).[228] AMCAP-IV is framed around upstream-to-downstream minerals development, sustainable practices and technology adoption, and capacity building across the value chain. That makes it a plausible vehicle for minerals-specific circularity commitments.

Regional coordination in nickel value chains is already advancing among private sector stakeholders. In February 2026, the Indonesian Nickel Miners Association (APNI) and the Philippine Nickel Industry Association (PNIA) signed a partnership agreement, witnessed by government officials from both countries, establishing the IndoPhil Nickel Corridor. Its priority areas are governance and regulatory coherence; ESG, EITI, and Sustainable Development Goals alignment; investment promotion and value-adding minerals; human capital and talent development; and community development and social acceptance. PNIA describes the partnership as initiated by industry but deliberately anchored in the ASEAN Principles for Sustainable Minerals Development adopted in October 2025.[229] Its organizing logic is complementarity in the primary chain, linking Philippine ore to Indonesian processing capacity, but its stated priorities do not extend to recovery, secondary materials, or reverse flows. The institutional architecture for regional nickel cooperation therefore exists, even though circularity sits outside it.

3.2.2 State of Play, Gaps, Challenges, Opportunities, and Recommendations of Policy, Legal, Regulatory, and Governance Circularity Frameworks in Indonesia

Indonesia's policy, legal, regulatory, and institutional landscape for circularity in the nickel value chain is uneven and still developing. The discussion below begins by assessing the national circular roadmap that underpins the regulatory landscape in Indonesia, and then examines this landscape in further detail across process circularity (Section 3.2.2(A)), product circularity (Section 3.2.2(B)), and governance (Section 3.2.2(C)), with the gaps, challenges, and opportunities identified in each area informing the recommendations that follow.

Indonesia's **national circular economy roadmap** (RAN-ES), which sits at the foundation of this landscape, currently does not include mining as a priority sector. The absence of mining from the roadmap means that process circularity in nickel production lacks an overarching policy framework that would set shared definitions, targets, and implementation pathways, coordinate across agencies, and create alignment between environmental, industrial, and climate policy. Elevating mining within the RAN-ES would enable a more integrated and resource-efficient approach to nickel production, moving beyond a compliance-driven model toward one that explicitly targets loss reduction and secondary material recovery across the mining and processing life cycle.

Priority sectors in the RAN-ES were selected on economic contribution, environmental impact, and data availability, and mining was excluded on the third criterion: circularity in mining is technically complex, tightly bound to the upstream extraction process, and sector-specific data remain very limited.[230] Elevating mining is therefore sequentially dependent on the characterization and disclosure measures recommended below, rather than an independent act of prioritization.

Further, the RAN-ES signals intent to develop EPR frameworks for electronics, including EV batteries, but does not establish the detailed institutional design needed for implementation (such as collection targets, financing models, enforcement mechanisms, or national reporting systems).[231] Translating the roadmap into a battery-specific regulatory package will be critical to operationalize product circularity across the full battery life cycle.

A. Process Circularity

Indonesia's current approach to process circularity in the nickel mining sector remains primarily oriented towards waste management, permitting, and compliance procedures. While recent policy developments signal growing attention to tailings management and by-product utilization, significant gaps remain in technical standards, data availability, enforcement capacity, and the integration of circular economy principles across the mining and processing life cycle.

Table 1 reflects the state of play of process circularity policies in Indonesia, assessing how each relevant policy instrument aligns with international best practices. The gaps, opportunities, and challenges behind each assessment are detailed in the discussion that follows. Alignment is rated on three levels:

1. Aligned: policy landscape is aligned with international best practice
2. Partial: some form of relevant regulation or standards exist but require strengthening or filling gaps
3. None: no relevant frameworks exist.

Table 1. State of play of process circularity policies in Indonesia

Policy category	Relevant policy instrument in Indonesia	Alignment with best practice
Circular economy roadmap	• Indonesia's National Roadmap and Action Plan: Circular Economy Indonesia 2025–2045 (RAN-ES)	None
Classification of waste, by-products, and secondary raw materials	• Government Regulation No. 22 of 2021 on the Implementation of Environmental Protection and Management	Aligned
Tailings management	• Government Regulation No. 22 of 2021 on the Implementation of Environmental Protection and Management • Government Regulation No. 37 of 2010 Regarding Dams • Ministry of Public Works and Housing Regulation No. 27 of 2015 Regarding Dams	Partial
Tailings reprocessing	• Ministry of Energy and Mineral Resources Regulation No. 26 of 2018 on the Implementation of Good Mining Practice and Supervision of Mineral and Coal Mining (Arts. 24, 25) • Ministry of Energy and Mineral Resources Decree No. 1827 K/30/MEM/2018 on Guidelines for the Implementation of Good Mining Practice, Annex VII	Partial
Slag valorization and industrial symbiosis	• Government Regulation No. 22 of 2021 on the Implementation of Environmental Protection and Management • Ministry of Energy and Mineral Resources Regulation No. 26 of 2018 on the Implementation of Good Mining Practice and Supervision of Mineral and Coal Mining (Arts. 24, 25) • Ministry of Energy and Mineral Resources Decree No. 1827 K/30/MEM/2018 on Guidelines for the Implementation of Good Mining Practice, Annex VII	Partial
Landfilling restrictions	• Government Regulation No. 22 of 2021 on the Implementation of Environmental Protection and Management	None
Post-mining land use, rehabilitation, and reclamation	• Law No. 4 of 2009 Mineral and Coal Mining, as amended by Law No. 3 of 2020 • Government Regulation No. 78 of 2010 on Reclamation and Post-Mining • Ministry of Environment Regulation No. 20 of 2025 concerning Standard Criteria for Environmental Damage to Land Resulting from Mining Operations and/or Activities • Ministry of Energy and Mineral Resources Regulation No. 26 of 2018 on the Implementation of Good Mining Practice and Supervision of Mineral and Coal Mining (Art. 1(12), Art. 22) • Ministry of Energy and Mineral Resources Decree No. 1827 K/30/MEM/2018 on Guidelines for the Implementation of Good Mining Practice, Annex VI	Partial

continued...

Policy category	Relevant policy instrument in Indonesia	Alignment with best practice
Water management	• Government Regulation 30 of 2024 regarding Water Resource Management.	Partial
Energy sources and efficiency	• Government Regulation No. 33 of 2023 on Energy Conservation • Ministry of Energy and Mineral Resources Regulation No. 8 of 2025 on Energy Management • Government Regulation No. 22 of 2021 on the Implementation of Environmental Protection and Management (AMDAL provisions)	Partial

Source: Prepared by the authors.

Process Circularity Gaps, Challenges, and Opportunities

Classification of waste, by-products, and secondary raw materials

Indonesia has taken an important initial step by reclassifying nickel slag as "non-B3 registered waste" once it meets certain technical thresholds,[232] creating a pathway for its use in road base, brick-making, and cement production without the administrative burden of hazardous waste permitting. This reclassification increased alignment with best practice and end-of-waste frameworks and represents an opportunity to build further.

Tailings management

Tailings management has become an issue of increasing priority in Indonesian policy. Tailings are classified as hazardous (B3) waste.[233] Indonesia has also signaled a shift away from deep sea tailings disposal, with a de facto halt on new permits since 2021, prompting a transition toward land-based filtered tailings storage ("dry stacking").[234] However, this shift has not yet been formally codified in law.[235] There is an opportunity to consolidate this policy direction through legislation explicitly prohibiting deep-sea tailings disposal.

In practice, implementing land-based filtered tailings storage has proven challenging in Indonesia (as discussed further in Section 3.1.2(A)). The rapid expansion of HPAL operations has resulted in waste volumes that now outpace available storage and safety infrastructure, contributing to numerous dam failures. From a regulatory perspective, several critical gaps remain. Current regulations[236] could be understood as being generally applicable to tailings storage facilities, but both focus on permitting procedures rather than enforceable engineering criteria.[237] Critically, there are no tailings-specific (and no *filtered tailings*–specific) safety regulations. Particularly, there are no minimum earthquake safety standards, required distances from communities and water sources, rainfall and flood design limits, quality controls for the filtering and compaction process, monitoring requirements, closure obligations, or rules requiring companies to disclose facility data and emergency plans.[238] The consequence-based design approach standard that is considered best practice, whereby facilities with potential for loss of life must be designed to withstand extreme flood and seismic events, is not systematically mandated in Indonesian regulation.[239]

HPAL expansion has outpaced Indonesia's regulatory capacity to manage its environmental and social impacts. In addition, even filtered tailings, the industry's current best available technology, carry inherent risks that cannot be fully engineered away, even under the highest safety standards.[240] Closing this gap requires not only stronger tailings-specific standards but also better coordination among agencies responsible for mining, the environment, and spatial planning, and participatory processes for agenda-setting, to ensure that industrial expansion decisions are evaluated against Indonesia's broader environmental, developmental, and societal priorities.

Tailings reprocessing

Tailings reprocessing remains in an early stage of development in Indonesia in practice. For instance, one producer is testing iron extraction from HPAL residues, which would yield a saleable product and reduce the volume requiring storage, and further investment in processing HPAL tailings to recover materials including sulfur has been reported.[241] However, Indonesia's legal framework for tailings reprocessing is considerably more developed than its practice. Under the mineral and coal conservation obligations,[242] holders of production and of processing and refining licences that generate processing residues must record the volume, element, and grade of minerals in those residues at their placement location, and must separately record which residues can be reused in another form and which can be reprocessed, reporting all of this in a periodic conservation report.[243] They must also place residues segregated by type and characteristic, control tonnage loss, and pursue utilization where economics or available technology permit reprocessing.[244]

Three features limit what these regulatory requirements deliver for nickel. First, the detailed retreatment trigger applies only to gold. Where gold residues meet defined criteria on grade, particle size, grade distribution data, and proximity to a processing plant, the holder must prepare a technical conservation study for retreatment and submit it as a special report.[245] No equivalent threshold, study requirement, or criteria set exists for nickel, so the regulatory architecture for moving from recorded data to an assessed reprocessing case is built and populated for one commodity and empty for another. Second, the utilization obligation is framed as an effort conditioned on economics or technology availability, which the operator assesses, with no threshold or independent verification. Third, tailings management and reprocessing reports go to the ministry, and there is no requirement to aggregate or publish them, so existing data cannot inform investment decisions by anyone outside the reporting company and the regulator.

The opportunity is to extend an existing regulatory framework by defining nickel-specific retreatment criteria on the gold model and by opening the resulting data, following the disclosure approaches taken in Australia, the EU, and Finland discussed above (Section 3.2.1).

An additional fundamental constraint is the lack of technical data on tailings composition, which limits the ability to assess the technical and economic feasibility of reprocessing pathways.[246] Because processing residues are classified as B3, obtaining a sample for research requires an environment ministry permit, which makes characterization studies and pilot projects materially harder to mount in Indonesia than in other jurisdictions.[247] The data the regulatory framework requires operators to record is therefore difficult for anyone outside those operators to generate independently.

Slag valorization and industrial symbiosis

As discussed above, Indonesia's reclassification of nickel slag as non-B3 registered waste has opened pathways for reuse. However, current frameworks do not just fail to promote industrial symbiosis; permitting confines reuse to the generating operator's own concession, which forecloses it, since symbiosis requires transfer between firms (Section 3.1.2(A)). There is an opportunity to introduce policy and fiscal incentives to encourage co-location or partnerships with cement manufacturers in industrial parks in order to develop stable demand for secondary materials.

Landfilling restrictions

Indonesia has no policy instruments restricting landfilling of nickel processing residues with recoverable value or requiring operators to demonstrate no viable recovery alternative exists before disposal is approved.[248] While the B3 waste management framework includes utilization, treatment, and disposal,[249] these are treated as equal options rather than a hierarchy.[250] Disposal is therefore not a last resort option. There are no landfill levies or disposal charges applicable to mining residues, meaning recovery and landfill carry identical regulatory and economic weight. For residues where secondary use is already marginal, such as lower-value nickel slag, this creates a structural bias toward disposal. Indonesia's B3 waste management framework provides a foundation on which sector-specific waste hierarchies and landfill restrictions could be built to shift incentives toward utilization.

Post-mining land use, rehabilitation, and reclamation

Indonesia has a reasonably detailed regulatory framework for mine site reclamation[251], requiring reclamation plans to be submitted at the production license stage,[252] *and* a 100% reclamation success rate before a license can be granted; it also establishes criminal penalties for licence holders whose permits are revoked or expire without reclamation and post-mining being carried out or the guarantee funds placed, and two mandatory guarantee funds—a reclamation guarantee during operations and a post-mining guarantee for final closure.[253] *Ministry of Environment Regulation No. 20 of 2025* marked a shift from qualitative to quantitative land damage assessment, defining damaged land by measurable thresholds including topsoil stockpile volume, erosion rates, and slope stability.[254]

Despite this framework, significant implementation gaps remain. Guarantee fund deposits are not a precondition for *Rencana Kerja dan Anggaran Biaya* (RKAB) approval (Work Plan and Budget authorizing operations to commence).[255] This means that companies can legally commence operations without depositing funds, and there is no legal procedure for when deposited funds prove insufficient to cover actual reclamation costs.[256] Shortfalls often occur because fund amounts are calculated based on company performance and financial capacity, rather than actual potential environmental damage, leading to arbitrary and widely varying valuations.[257] A further structural problem is that the definition of reclamation activities under the regulation is (and has been, in practice) broad enough to allow companies to avoid genuine pit rehabilitation by redesigning open pits for other uses such as water sources or tourism areas, without carrying out substantive environmental restoration.[258] The mechanism sits in the implementing guidance: reclamation by revegetation is assessed against prescribed success criteria and carries a minimum three-year maintenance obligation, whereas reclamation to any other permitted designation is assessed against criteria the licence holder itself proposes, with no equivalent aftercare.[259] The rigor of the obligation therefore depends on the designation chosen, and the operator both selects the designation and proposes the standard it will be judged against.

Beyond addressing these specific implementation gaps, there is also an opportunity to move beyond compliance-focused reclamation toward a more strategic approach to post-mining land use. Indonesia's current framework is oriented primarily toward revegetation and ecological restoration and does not require early, site-specific assessments of beneficial post-mining land uses such as renewable energy, sustainable agriculture, nature restoration, or other community-oriented purposes, as part of the feasibility and planning processes, so alternative designations arise as a discretionary election at the reclamation stage.

A separate regime applies to processing and refining facilities. Holders of processing and refining licences must prepare a post-operation plan with success criteria covering the processing or refining facility, supporting facilities, and monitoring, and any shortfall in the cost of completing post-operation remains their responsibility.[260] Notably, post-operation carries no equivalent to the reclamation and post-mining guarantee funds required of mining licence holders, so the obligation to restore a smelter or HPAL site is not financially secured in the way a mine site is.

Water management

Indonesia's general framework for water resource management[261] prioritizes community and agricultural needs over commercial use and requires water use approvals for mining operations.[262] Some companies are already going beyond this baseline, for example, by investing in water recycling and reuse infrastructure as part of their operations.[263] However, operations are not yet required to submit site-specific water management plans, publicly report on water consumption for recycled volumes, or restrict freshwater withdrawals during periods of water stress.

Energy sources and efficiency

Indonesia's nickel processing is energy-intensive and mostly powered by captive coal.[264] Its general energy efficiency framework obliges energy users above defined consumption thresholds, including industrial users above 4,000 metric tons of oil equivalent per year, to appoint energy managers, conduct periodic energy audits, prepare energy efficiency programs, and implement audit recommendations within three years.[265] Though a plausible vehicle for energy circularity in nickel processing, the framework is directed at consumption efficiency rather than at recovery: nothing in it requires or rewards the capture and reuse of waste heat, and the audit obligation does not extend to identifying recoverable process energy.

The circularity-specific opportunity is energy recovery within facilities: HPAL operations generate recoverable heat as steam, and capturing it as an energy source is already demonstrated and happening in siloed operations in Indonesia. One producer feeds steam from sulfuric acid production into mineral extraction, reducing by 50% the power plant capacity it requires and approaching shutdown of the plant, and is building a second plant to convert excess steam to power.[266] The steam substitution potential for HPAL has been put at around 70% of coal use.[267]

A specific regulatory friction is that design changes to enable heat capture may trigger a new environmental impact assessment (*Analisis Mengenai Dampak Lingkungan,* AMDAL), which can act as a disincentive to efficiency upgrades.[268]

Process Circularity Recommendations

Circular economy roadmap

- Elevate mining and nickel processing as a priority sector within Indonesia's National Circular Economy Roadmap and Action Plan (2025–2045), with dedicated targets, implementation pathways, and assigned agency responsibilities for process circularity across the mining and processing life cycle.

Classification of waste, by-products, and secondary raw materials

- Build on the reclassification of nickel slag as non-B3 registered waste by developing sector-specific technical thresholds and end-of-waste criteria for additional nickel processing residues, including HPAL residues where technically justified, to progressively expand the range of materials that can enter secondary use pathways without hazardous waste permitting burdens.
- Introduce a regular review mechanism for waste classifications to ensure classifications remain aligned with evolving processing technologies and secondary use markets.
- Pursue mutual recognition of Indonesia's waste and by-product classifications with ASEAN Member States, so that nickel processing residues certified domestically as non-B3 registered waste or designated as by-products can enter secondary use markets regionally without re-establishing their status in each destination, using the bilateral, multilateral, or regional agreement mechanism available under Article 11 of the Basel Convention.

Tailings management

- Formally codify the de facto halt on new deep sea tailings disposal permits through an explicit legislative prohibition, providing legal certainty for operators and communities.
- Develop tailings-specific technical standards, covering: minimum factors of safety under seismic and flood loading; setback distances from downstream communities, infrastructure, and water sources; filtering, dewatering, and compaction quality control requirements for dry-stacked facilities; closure and long-term stability standards; and mandatory public disclosure of facility data, dam break analyses, and emergency response plans.
- Adopt a consequence-based design approach as a mandatory standard for tailings storage facilities where failure would result in loss of life, requiring such facilities to be designed to withstand extreme flood and seismic events.
- Strengthen cross-agency coordination between the Ministry of Energy and Mineral Resources, the Ministry of Environment and Forestry, and spatial planning authorities to ensure that HPAL expansion decisions are evaluated against environmental carrying capacity and downstream community risk.

Tailings reprocessing

- Establish nickel-specific criteria triggering a mandatory technical study for reprocessing, parallel to those already in force for gold residues, calibrated to nickel content in HPAL residues and ferronickel slag, and to Indonesian placement and proximity conditions.
- Define the methodology, minimum parameters, and sampling frequency for recording the volume, element, and grade of nickel processing residues, so that the existing recording obligation produces data of a quality sufficient to support a reprocessing investment case.
- Exempt or fast-track sample quantities and pilot-scale volumes of processing residues from full hazardous waste permitting, through the B3 regime, currently subject to handling and reporting conditions, so that characterization studies and reprocessing pilots can be mounted without a permitting process designed for commercial waste movement.
- Require that tailings management and reprocessing report data be aggregated into a national inventory and disclosed at a level allowing potential off-takers, researchers, and regulators to assess reprocessing potential, following the approaches taken in Australia, the EU, and Finland.
- Replace the self-assessed test of economic or technological feasibility with defined criteria and periodic independent verification, so that a reprocessing or utilization obligation conditioned on the operator's own judgment becomes reviewable by a government entity.

Slag valorization and industrial symbiosis

- Introduce fiscal and regulatory incentives to promote industrial symbiosis between nickel processing facilities and downstream users such as cement manufacturers, including, for example, co-location incentives within industrial park licensing frameworks and preferential access to industrial park infrastructure for facilities with demonstrated secondary material offtake arrangements.
- Remove the permitting restriction confining reuse of registered non-B3 residues to the generating operator's own concession.

Landfilling restrictions

- Establish a sector-specific waste hierarchy for nickel processing residues, positioning disposal as a last resort option available only where the operator has demonstrated that no technically and economically viable recovery or utilization alternative exists.

- Introduce a disposal levy or landfill charge applicable to nickel processing residues with recoverable value, set high enough so that disposal costs more than recovery, and escalating on a published schedule so operators can plan against it.

Post-mining land use, rehabilitation, and reclamation

- Make reclamation guarantee fund deposits a mandatory precondition for RKAB approval.
- Revise the methodology for calculating reclamation guarantee fund values to anchor fund amounts to independently assessed environmental restoration costs.
- Require early, government-led site-specific assessments of beneficial post-mining land uses, including renewable energy, sustainable agriculture, nature restoration, and community-oriented purposes, as part of the feasibility and planning processes. These assessments should inform and guide companies' post-mining reclamation obligations.
- Tighten the regulatory definition of reclamation to require substantive environmental restoration, and amend the broad alternative designation provisions that have allowed for circumventing rehabilitation requirements.
- Extend financial assurance to processing and refining facilities, requiring a guarantee fund to back post-operation obligations for the restoration of smelter and HPAL sites.

Water management

- Introduce site-specific water management plan requirements, public reporting of water consumption and recycled water volumes for mining and processing operations, and freshwater withdrawal restrictions where relevant.

Energy sources and efficiency

- Extend the energy audit obligation to cover recoverable process energy, so that mandatory audits identify waste heat and other recoverable streams in addition to consumption efficiency, and so that the resulting recommendations, which operators must implement within three years, capture energy circularity measures.
- Establish a proportionate, expedited environmental review pathway for circularity and efficiency retrofits (such as HPAL waste heat capture) that pass a net environmental benefit screen, with retained full review for changes carrying material new impacts and mandatory post-implementation monitoring.
- Make energy recovery a permitting expectation for new and expanding processing facilities

B. Product Circularity

Southeast Asia is projected to face on the order of 2,166 GWh of used batteries by 2040, while Indonesia recycled only around 17% of the 2 million metric tons of e-waste it generated in 2021.[269] Product circularity policy frameworks for batteries remain at an early stage in Indonesia. While the national circular economy roadmap signals intent to develop EPR frameworks for electronics, including EV batteries, there is a need to introduce a robust battery specific product circularity policy package, as discussed in this section.

Table 2 reflects the state of play of product circularity policies in Indonesia, assessing how each relevant policy instrument aligns with international best practice. The gaps, opportunities, and challenges behind each assessment are detailed in the discussion that follows. Alignment is rated on three levels:

1. Aligned: policy landscape is aligned with international best practice
2. Partial: some form of relevant regulation or standards exist but require strengthening or filling gaps
3. None: no relevant frameworks exist.

Table 2: State of play of product circularity policies in Indonesia

Policy category	Relevant policy instruments	Alignment with best practice
National circular economy roadmap	• Indonesia's National Roadmap and Action Plan: Circular Economy Indonesia 2025–2045	Partial
Extended Producer Responsibility	• Law No. 18 of 2008 on Waste Management • Government Regulation No. 81 of 2012 on Management of Household Waste and Similar to Household Waste • Ministry of Environment and Forestry Regulation No. 75 of 2019 on the Roadmap for Waste Reduction by Producers • Government Regulation No. 27 of 2020 on Specific Waste Management • Ministry of Environment and Forestry Regulation No. 6 of 2021 on Procedures and Requirements for the Management of Hazardous and Toxic Waste (B3) • Ministry of Environment and Forestry Regulation No. 9 of 2024 on the Management of Waste Containing Hazardous and Toxic Materials and Hazardous and Toxic Waste • Presidential Regulation No. 55 of 2019 on Accelerating Programs of Battery Electric Vehicles for Road Transportation • Presidential Regulation No. 79 of 2023	Partial
Producer Ownership	• Ministry of Energy and Mineral Resources Regulation No. 1 of 2023 on the Provision of Electric Charging Infrastructure for Battery-Based Electric Motor Vehicles • Law No. 18 of 2008 on Waste Management • Government Regulation No. 81 of 2012 on Management of Household Waste and Similar to Household Waste • Ministry of Environment and Forestry Regulation No. 75 of 2019 on the Roadmap for Waste Reduction by Producers • Government Regulation No. 27 of 2020 on Specific Waste Management • Ministry of Environment and Forestry Regulation No. 6 of 2021 on Procedures and Requirements for the Management of Hazardous and Toxic Waste (B3)	Partial
Circular product design	• Law No. 20 of 2014 on Standardization and Conformity Assessment • Ministry of Industry Regulation No. 69 of 2024 regarding the Mandatory Implementation of Indonesian National Standards for Primary Batteries • Law No. 3 of 2014 on Industrial Affairs	Partial

continued...

Policy category	Relevant policy instruments	Alignment with best practice
Labeling and digital battery passports	• Law No. 20 of 2014 on Standardization and Conformity Assessment • Ministry of Industry Regulation No. 69 of 2024 regarding the Mandatory Implementation of Indonesian National Standards for Primary Batteries • Law No. 3 of 2014 on Industrial Affairs	None
Targets and standards for secondary use	• Law No. 18 of 2008 on Waste Management • Government Regulation No. 81 of 2012 on Management of Household Waste and Similar to Household Waste • Ministry of Environment and Forestry Regulation No. 75 of 2019 on the Roadmap for Waste Reduction by Producers	None

Source: Prepared by the authors.

Product Circularity Gaps, Challenges, and Opportunities

Extended Producer Responsibility (EPR)

Elements of producer responsibility exist within Indonesia's broader waste policy framework, but are not structured as a dedicated battery EPR scheme. The law introduces the concept of producer responsibility for waste reduction and handling,[270] and implementing regulations set out producer obligations related to take-back and environmentally sound product design for household and household-like waste;[271] and to develop waste reduction roadmaps for certain product categories.[272] A battery-specific provision also exists outside the waste framework, requiring that EV battery waste be handled through recycling or other management[273]—but without designating a responsible producer, setting collection or recovery targets, establishing financing mechanisms, or creating take-back obligations.

While these instruments reflect elements of an upstream shift of responsibility and incentives for improved product stewardship by producers, they are primarily oriented toward household and consumer waste streams.[274] This framework does not establish any battery-specific take-back or financing mechanisms, nor does it create any clear national targets or a functioning PRO architecture for batteries.

Battery end-of-life management is currently anchored primarily in Indonesia's specific waste and hazardous waste (B3) rules, which divide by the source of the material:

- B3 waste arising as residue from business activity, including batteries handled at industrial scale is governed by a licensing regime covering storage, collection, transport, utilization, and treatment.[275]
- Waste containing B3 arising from households, commercial premises, and public facilities is governed by a separate regime, which expressly excludes process residues from business activity.[276]

Accordingly, a used battery discarded by a consumer and one arising from a processing operation fall under different regimes with different obligations. These regulations allocate distinct responsibilities for handling hazardous waste across stakeholders such as waste generators, licensed transporters and processors, and local authorities, and focus on compliance requirements and permitting for controlled handling instead of specific circularity incentives. While essential for safety and environmental protection, this framework does not ensure high collection rates, create predictable secondary material markets, or shift costs upstream to producers. Nor does it impose producer-led take-back obligations for batteries comparable to those that apply under policies governing household or consumer waste streams. The division by source is itself a gap for battery circularity, since an EV battery moves from consumer possession to industrial processing across its end-of-life pathway and therefore crosses between the two regimes, with no instrument establishing continuity of obligation across the handover.

The classification also carries a cost consequence. Battery waste is listed as B3, so collection, transport, utilization, and processing each require permits and licensed handlers.[277] Those requirements are appropriate to the hazard, but licensed capacity is concentrated on Java while batteries retire across the archipelago, so the compliance premium rises with distance from where that capacity sits, and bears most heavily where informal collection is most established and enforcement weakest. The framework is therefore a workable compliance backbone for a battery EPR scheme, as argued above, only if the cost asymmetry it creates is addressed alongside it (Section 3.3).

Despite these gaps, the existing hazardous waste permitting infrastructure can serve as the compliance backbone for a battery-specific EPR scheme, since requirements for safe handling are already in place. Additional implementing regulations and guidelines specific to batteries could clarify who qualifies as a producer, require registration and reporting of placed-on-market volumes, set collection and recycling targets by battery type, require producers to institute take back and collection systems, and enable collective compliance through a regulated PRO model, bringing Indonesia closer to the approach seen in jurisdictions like the EU,[278] India,[279] and South Korea.[280] This approach would reduce reliance on municipalities and fragmented voluntary schemes and could help close leakage pathways.

Because Indonesia would be building a PRO architecture rather than reforming one, the design conditions set out in Section 3.2.1 can be built in from the start. The following four conditions apply: accreditation and licensing of PROs against defined operational and reporting standards; mandatory public reporting of fees collected and of tonnages by treatment route; independent third-party audit of that reporting; and eco-modulated fees set against a regulator-defined floor, so that differentiation is large enough to influence design rather than collapsing toward uniform cost recovery.[281]

Moving towards producer ownership through leasing and servitization (including BaaS):

Indonesia's producer ownership frameworks are very incipient and still require structuring. Indonesia has built the infrastructure a BaaS model would need without establishing the ownership framework that would make it one. Current laws regulate public battery swapping stations as electricity supply infrastructure; they also license the operators and grant them tariff relief.[282] A commercial swap market for electric motorcycles has developed on that basis, with 1,882 stations recorded as of June 2024.[283] What the framework does not address is ownership: nothing establishes whether a producer retaining title to a battery across multiple cycles remains the waste holder under the B3 regime. Therefore, establishing a battery swap framework is an incipient first step towards a BaaS business model, but still insufficient to enable circularity.

Circular product design

Indonesia currently has limited policies to incentivize or require circular product design. Primary batteries must comply with internationally referenced technical standards and be certified under the Indonesian National Standard (*Standar Nasional Indonesia,* SNI) scheme.[284] While the government has developed SNI standards relevant to EV batteries and other secondary batteries, there is no clearly established, universal mandatory SNI certification requirement for these products comparable to the mandatory scheme for primary batteries.[285]

SNI requirements governing batteries also largely focus on physical and electrical specifications, performance metrics, safety testing, and quality assurance.[286] As a result, while these standards help ensure product quality and help protect consumers and markets, they do not include design criteria that explicitly support modular durability, recyclability, reusability, or material efficiency. Further, while battery manufacturers may incorporate environmental performance considerations through the Green Industry certification, the scheme primarily certifies production processes and the business, but not the product.[287]

Labeling and digital battery passports

Indonesia does not have mandatory digital battery passport requirements. There are no specific Indonesian regulations requiring digital battery passports, or other traceability tools relevant for EPR enforcement, second-life decisions, and credible recycled content claims. Existing labeling requirements merely signal compliance with relevant SNI standards.[288] Given the limited focus of SNI standards on product safety and performance, such labels do not provide clear information about a product's durability, recyclability, or repairability.

Indonesia can pursue an incremental approach to digital battery passports, starting with EV batteries and industrial applications, where the number of actors is smaller and traceability requirements can be enforced through licensing, registration, and supply chain reporting. Over time, these traceability approaches could support verification of recycled content, improve second-life use decisions, and strengthen enforcement against informal and non-compliant handling. Whether those benefits materialize depends on creating the comprehensive enabling environment for this policy intervention, since information alone does not create circularity, (conditions set out in Section 3.2.1), which Indonesia does not yet have: no second-life certification pathway, and licensed collection capacity concentrated on Java. The technical challenges on grading, battery composition and performance data, as set out in Section 3.1.3, will need to be considered as well.

Targets and standards for secondary use

Indonesia does not have battery-specific quantitative circularity targets around collection and recovery or recycled content mandates. Instead, the regime is largely procedural in nature, focusing primarily on permitting (especially under the hazardous waste management regime).[289] For instance, the hazardous waste management framework introduces general producer responsibility concepts without mandating rates or thresholds.

The gap extends to second-life use, which the framework neither enables nor rewards. Indonesia has no established pathway by which a retired battery assessed as retaining usable capacity can be repurposed and placed back on the market, no testing or certification regime through which the performance and safety of such a product could be verified, and no demand-side measure that would create a market for one. Part of the obstacle is classification: end-of-life batteries are handled as B3 waste under a permitting regime built for controlled disposal, so retaining function requires navigating a change of status. The regulatory default is therefore recovery of materials rather than retention of function, which forgoes the higher-value use that best practice would prioritize (Section 3.2.1).

Product Circularity Recommendations

Battery-specific circularity regulations

- Issue a battery circularity regulatory package, consisting of implementing government and ministerial regulations to translate the national circular economy roadmap into operational rules across the battery life cycle.

- Define covered battery categories and align obligations associated with various battery types to associated risks, opportunities for circular economy integration, and feasibility.

Extended Producer Responsibility (EPR)

- Establish battery-specific EPR obligations., building and expanding on the concept of producer responsibility, including by:
  - Making upstream responsibility explicit, such that producers are responsible for take-back, collection, financing, and verified treatment of batteries, even if they contract third parties.
  - Introducing eco-modulated EPR fees that vary by recyclability and recoverability, so that producers whose batteries are designed for disassembly, component replacement, and material recovery pay lower fees than those whose are not, so that producers whose batteries are designed for disassembly, component replacement, and material recovery pay lower fees than those whose are not, addressing the design gap that flat EPR fees leave open.
  - Introducing other requirements around mandatory digital product passports, recycling and collection targets, and minimum recycled content requirements.
- Use the existing hazardous waste management framework as the compliance backbone, linking EPR compliance to existing licensed transport and treatment pathways and auditable reporting, while addressing the cost asymmetry that framework creates, so that compliance obligations are proportionate to risk, and so that permitting does not make the compliant route uneconomic in regions distant from licensed capacity.
- Introduce a tiered handling regime for end-of-life batteries, differentiating storage, transport, and permitting requirements by condition, chemistry, and assessed risk, and providing a lighter-touch pathway for intact packs destined for testing or repurposing, calibrating hazard controls to hazard.
- Regulating the PRO function through accreditation and licensing against defined operational standards, mandatory public reporting of fees collected and tonnages by treatment route, independent third-party audit, and a regulator-set floor on fee modulation, so that collective compliance shifts producer decisions.

Producer ownership

- Treat EPR and producer ownership as sequential and define the conditions under which the transition should advance. Establish EPR obligations first, then set out in the same instrument the thresholds that would justify moving from producer responsibility toward producer ownership for a given battery category.
- Remove legal obstacles to producer ownership by clarifying that retained ownership of a battery does not transfer waste-holder obligations to the user, and that a producer retaining ownership across multiple cycles remains the responsible party for end-of-life handling. Ownership models cannot be piloted while the allocation of liability under the hazardous waste regime is unresolved.
- Incentivize BaaS by strengthening Indonesia's current battery swapping framework in a way that recognizes the battery and the vehicle as separately owned in registration and tax treatment, and set an interoperability standard for swap systems.

Circular product design

- Extend mandatory SNI compliance requirements beyond primary batteries, starting with EV and industrial batteries.

- Add phased circularity requirements to mandatory SNI standards, introducing requirements such as consideration of life-cycle emissions at the design stage, use of designs that promote modular durability (taking into account technological risk), enabling reusability and recyclability, and material efficiency.
- Align Green Industry certification requirements to reward verified take-back participation and circular production practices.

Labeling and digital battery passports

- Introduce phased labeling and digital battery passport requirements to operationalize traceability across the battery life cycle, building on the existing labeling baseline. As a first step, the government can require digital battery passports (with a minimum data set) for EV and industrial batteries, where a smaller number of actors makes enforcement more feasible.
- Over time, the digital passport system should capture all core circularity and compliance information, such as battery type, chemistry, producer, importer (if any), date placed on market, ownership status, repair or refurbishment history, and verified transfer to licensed handlers. Requirements can then be expanded to additional battery categories and linked to national reporting systems, while protecting commercially sensitive information and enabling verification through registration and supply chain reporting.

Targets and standards for secondary use

- Set phased, battery-specific collection and material recovery targets, anchored in the battery EPR instrument, with clear escalation over time, and define compliance so that verified repurposing for second-life use counts toward collection targets.
- Introduce minimum recycled content requirements for new batteries, phased by chemistry and type, implemented through Indonesia's SNI certification framework and linked to producer reporting under EPR.
- Adopt quality standards for secondary battery materials and second-life use so that depleted batteries, recycled metals, and by-products can be reliably traded and reused across industries.
- Upgrade recycling permits to include performance standards (minimum recovery efficiencies and verification), using the existing licensing backbone.
- Establish a dedicated tariff classification for used batteries, so they can be distinguished from waste at the border and mutual recognition of end-of-waste criteria can be given customs effect.

Sequencing recovery capacity

- Stage battery recovery capacity, beginning with collection, storage, and pre-treatment to black powder, and treating post-treatment metal extraction as a subsequent phase contingent on regulatory maturity and market development. Pre-treatment carries a lower capital and environmental burden and can build collection systems, safety practice, and supply chain reliability (Section 3.1).
- Clarify the respective roles of the state and the private sector in that sequence, including whether storage and pre-treatment hubs are publicly operated, as proposed in the KSP-GGGI work on Indonesia's recycling capacity, with metal extraction and material production led by the private sector.
- Secure market access for intermediate output as part of the staging decision, since a pre-treatment-focused model depends on being able to sell black powder into external markets, which makes the classification and mutual recognition measures recommended above a precondition for the sequence (Sections 3.2.1 and 3.3).

Creating a market for secondary use

- Require an assessment of second-life suitability before recycling is authorized for EV and industrial batteries, so that packs retaining usable capacity are routed to repurposing rather than material recovery, drawing on the state-of-health data captured through the digital battery passport requirements recommended above.
- Build domestic demand for repurposed batteries through public procurement preferences for second-life storage in grid and off-grid applications and through fiscal incentives for energy storage projects that incorporate them.
- Establish testing and certification requirements for repurposed batteries to assure their performance or safety.

C. Governance

Governance Gaps, Challenges, and Opportunities

A central challenge is the gap between policy ambition on one hand, and enforcement mechanisms and implementation capacity, on the other. Indonesia's governance frameworks on circular economy tend to be under-implemented and under-enforced due to limited enforcement capacity, weak monitoring systems, and practical difficulties in verifying compliance across a diverse range of stakeholders.[290] Credible enforcement and data systems are needed for circularity frameworks to generate outcomes. The tailings management and reprocessing regime illustrates the pattern, where operators are required to record the element and grade of processing residues, but the resulting data is neither specified to a usable standard nor disclosed; the obligation produces information nobody can use (Section 3.2.2(A)).

The failure to enforce reclamation and post-mining rehabilitation obligations also illustrates this gap. Companies report on their reclamation efforts annually, but there is no standardized inspection timeline, no standard cost for ground inspections, and no clear framework for how submitted reports are assessed. As of 2018, more than 60% of companies holding mining concession licenses had not deposited the required reclamation or post-mining guarantee funds.[291]

These enforcement weaknesses are compounded by structural deficits in corporate accountability. Indonesia's legal framework does not restrict operators from using subsidiary structures to isolate closure liabilities or from transferring assets to undercapitalized entities in ways that extinguish those obligations.[292] Laws on limited liability companies and bankruptcy uphold general principles of limited liability without environmental carve-outs, enabling the reclamation liability to be stranded with entities that cannot meet it.[293] At the operational level, there is no requirement for corporate boards to bear primary legal and financial accountability for environmental safety outcomes,[294] meaning that accountability can be delegated downward through management structures in ways that allow liability to remain diffused and unenforceable.

A further structural gap is the absence of mandatory public disclosure obligations. Mining companies are required to report to government agencies,[295] but there is no requirement to make that information publicly available. International benchmarking efforts around mine waste management have found that Indonesia scores negatively across virtually all public information categories, as there are no requirements to disclose facility names, locations, or operational footprints; no mandatory public availability of AMDALs, design documents, closure plans, or financial assurance documentation; and no post-failure disclosure requirements.[296] Without public access to this information, communities, civil society organizations, and investors cannot independently assess whether environmental or circularity commitments are being met, and regulators lack the information needed to design policy against actual conditions and to adjust it as those conditions change. The case for disclosure is not accountability. Targets set for the sake of it, without data on residue composition, volumes, or treatment routes are arbitrary, and meeting an arbitrary target demonstrates nothing, and archives no real outcomes on circularity. This disclosure gap also creates a risk of progressive opacity in reporting.

Institutional fragmentation and coordination challenges also pose risks. Battery circularity, for instance, spans multiple agencies and governance levels, and implementation requires consistent operational rules at the subnational level.[297] Without clear mandates and coordination mechanisms, responsibilities become diffused, compliance uneven, and investment signals weakened. The absence of a single point of accountability across agencies responsible for mining, environment, land use planning, and others further limits the government's capacity to respond coherently to emerging regulatory challenges.

Governance Recommendations

- Establish standardized inspection timelines, a published framework for how annual reclamation reports are assessed, and standard costing for ground inspections.
- Introduce environmental carve-outs to limited liability so that closure and rehabilitation obligations cannot be extinguished by transferring assets to undercapitalized entities, and assign primary legal and financial accountability for environmental safety outcomes to corporate boards, prohibiting downward delegation.
- Mandate publication of facility names and locations, AMDALs, closure plans, and financial assurance documentation, together with post-failure disclosure, to provide communities, investors, and regulators the basis to verify compliance.
- Designate a single institutional home for circular economy policy. Circularity currently spans mining, environment, industry, investment, and planning authorities with no single point of accountability. Assign lead responsibility to one entity, with a defined mandate to coordinate across ministries and to issue consistent operational rules at the subnational level.

3.3 Economic and Financial Enabling Conditions

3.3.1 Costs

Overview of Best Practices in Circularity Costs

The economics of circularity are uneven, and this nuance is central: some circular interventions in the nickel value chain reduce costs or open new revenue streams, while others impose net costs that the market will not finance without support.

On the favorable side, process circularity measures such as resource-efficient extraction, water reuse, and nickel by-product valorization can lower input, disposal, and liability costs, and several of them—advanced geometallurgy, ferronickel slag to construction materials (revenue-positive within a concession, though not yet tradable between firms; see Section 3.1.2), and waste heat recovery at HPAL plants—can be revenue-positive where offtake and logistics align.[298]

On the unfavorable side, many nickel product-circularity and advanced reprocessing pathways currently face a bankability gap.[299] Reverse logistics, collection, safe storage and transport of hazardous end-of-life batteries, and the capital cost of hydrometallurgical recovery can exceed the value of recovered nickel at current prices and volumes—particularly while nickel prices are depressed by oversupply and before a domestic secondary material market exists. Best practice therefore treats the cost barrier as a sequencing and risk-allocation problem: governments use targeted fiscal instruments (tax relief, accelerated depreciation, levies that internalize disposal costs), public procurement to create demand, and blended finance and de-risking tools to make first-mover circular investments viable, while phasing obligations so that markets mature before mandates bind.[300]

A complementary best practice is the shift from selling nickel as a commodity to providing it as a service. Servitization models—including MaaS (see Box 2) and BaaS (see Box 1)—change the cost calculus by retaining ownership of the product (either metal or battery) with the producer, so that design choices, durability, recovery, and reuse of nickel-bearing products protect revenue (Section 3.2.1).

Box 2. Metals-as-a-Service (MaaS): an ownership model for circularity

What it is. In a conventional sale, ownership of the metal passes to the buyer, and the producer's interest in it and accountability for it end. MaaS reverses that logic. Ownership stays with one segment of the value chain, and what transfers to the next is the right to use the metal, together with a contractual duty to ensure it can be recovered. The metal is leased and returned to the owner in its original form when the contract ends.[301]

Why it changes behavior. That single change reorders incentives. Because the owner of the metal gets the metal back at the end of its life cycle, recovery becomes an asset to protect rather than a cost to absorb, and design for disassembly and reverse logistics become commercial priorities. The owner becomes responsible for that metal, guaranteeing that it is brought back to the economy and preventing it from becoming waste. By acting on the metal held in an asset, the model reaches applications that recycling does not; for example, it does not require separating the nickel from the steel at end of life.[302]

The mechanism that makes this work is a special purpose vehicle (SPV). Rather than the producer holding metal on its own balance sheet indefinitely, a dedicated entity owns the metal, leases use rights to the asset operator, coordinates recovery with recyclers at end of contract, and then re-leases the recovered material into the next asset. The stock it accumulates functions as a metals bank, aggregating primary and secondary supply into an asset base rather than dissipating it through one-time sales, and generating revenue streams that can be securitized.[303]

Why it can pay. The case is not only environmental. For the user, the metal shifts from capital expenditure to operating expenditure, lowering upfront cost and improving supply security.[304] Modelling of steel in a 400 MW onshore wind project found the capital cost of the project fell by roughly 20%, the levelized cost of the electricity it produced by around 15%, and the developer's return improved relative to the risk it carried.[305]

Relevance and potential application in Indonesia. Most of Indonesia's nickel is used as an alloy in steel manufacturing. Around 83% of 2025 nickel production went into the nickel-bearing stainless steel sector against 17% entering the EV battery supply chain.[306] A MaaS business model that works on steel in wind therefore addresses the majority of Indonesia's nickel output. Applying it in practice will not require Indonesia to host the wind projects; it will require Indonesian nickel, ferronickel or steel producers to participate as owners of the steel used in wind turbine assets elsewhere, which is what an ownership model makes possible.

A second potential candidate for Indonesia: geothermal. Geothermal offers a potential domestic application of the same business model. Nickel-bearing stainless and corrosion-resistant alloys are standard in geothermal plants. A single plant may contain on the order of 100 tons of nickel,[307] and the metal sits in fixed infrastructure for decades. The cost barrier is well documented: high-nickel alloys are often too expensive for deep-seated geothermal, and their price volatility complicates project cost estimates.[308] That is the barrier an ownership model is designed to address, by moving the metal off the developer's capital budget and shifting metal price risk to the party best placed to carry it. Much of the surrounding value chain is already vertically integrated through state entities, with geothermal resource risk coverage available through PT SMI and PLN as offtaker.

What would need to be established. The application in geothermal is a candidate configuration, not an assessed opportunity, and no financial analysis has been undertaken for it. Three questions would determine feasibility: whether Indonesian geothermal alloy volumes are sufficient to support a leasing vehicle; which entity would hold ownership, and on what balance sheet; and whether the cost of capital for a state-linked lessor is competitive with outright purchase. Practitioner consensus is in any case that a single MaaS model spanning an entire critical minerals value chain is unlikely to be viable, and that effort should concentrate on shorter, commercially promising segments.[309] Nickel-bearing geothermal alloys may be one such segment.

State of Play of Circularity Costs in Indonesia

Indonesia's nickel economics are presently organized around rapid primary expansion rather than circularity. The economic logic of HPAL is a circularity-adjacent one—it converts low-grade limonite ore, previously treated as waste, into battery-grade product (Section 3.1)—but the dominant business model captures value through volume and downstream integration, not through closing material loops. Where circular practices have emerged, they have done so where they are already cost-saving or revenue-generating at the firm level: PT Vale's substitution of slag for stone aggregate in its own road construction, and Trimegah Bangun Persada's conversion of slag into bricks for internal use and prospective sale, are both driven by avoided disposal and storage costs.[310]

Regulation bears on these economics in the opposite direction on the product side. Because end-of-life batteries are classified as B3 waste, collection, transport, utilization, and processing each require permits and licensed handlers,[311] and licensed hazardous waste capacity is concentrated in Java and a few industrial centers (Section 3.3.2). A generator elsewhere in the archipelago therefore faces transport and compliance costs on the legal route that can exceed the value of the material recovered. The classification is warranted on hazard grounds, but its present design means the compliant route is costliest where formal capacity is thinnest.

Gaps, Challenges, and Opportunities of Circularity Costs in Indonesia

Indonesia's policy framework distorts the relative economics of circularity in two directions. It does not price disposal or reward recovery, so the relative economics default toward landfilling and primary production (Section 3.2.2). In addition, transactions in domestically produced mineral material are taxed while downstream industries can import material under tax holidays, so recovered domestic material competes against imports at a structural price disadvantage.[312] The opportunity is to use low-cost, near-term instruments—industrial symbiosis matchmaking and co-location incentives, end-of-waste pathways that remove permitting cost from proven secondary materials, and disposal levies—to tilt the economics toward circularity for interventions that are already close to viable, such as slag valorization, which is constrained by permitting, not economics.

The challenge is that the higher-cost interventions—battery collection and recovery and tailings reprocessing—are not yet bankable in Indonesia, and may not become so until sufficient volumes are aggregated, which the evidence suggests will not occur within a single national market.[313] Part of that gap is regulatory in origin rather than intrinsic to the technology or the market, since the compliance cost structure described above is a policy design outcome and is therefore addressable (Section 3.2.2).

There is not a blanket "circularity reduces costs" claim, as the cost profile is intervention-specific (Section 2). The appropriate response is phased: enable and de-risk the low-cost, revenue-positive measures while building the data, standards, and demand signals (procurement, recycled-content targets) that will make the capital-intensive measures financeable later.[314]

A further constraint on this sequencing is that it treats the addressable market as domestic. The market a recovered ton can reach is set by rules on cross-border movement and material classification as much as by Indonesian demand, and those rules are largely regional (Section 3.2.1). Mutual recognition of end-of-waste criteria and harmonized classification of secondary raw materials across ASEAN would enlarge the market for slag-derived construction materials and recovered battery metals without waiting for domestic demand to mature, which makes it a lever that acts on market size, not unit cost. It also shortens the horizon over which capital-intensive recovery becomes bankable, since recovery plants depend on throughput and a regional catchment supplies volume a single national market cannot (Section 3.3.2).

Finally, finance is a critical enabler of circularity. The companion applied research paper, Financing Indonesia's Green Industrialization: System Pathways, Structural Diagnosis, and Tailored Solutions, addresses the instruments that respond to the cost and bankability barriers diagnosed above, including blended finance and de-risking structures, concessional and patient capital, minimum volume guarantees, and dedicated circular credit facilities.

Recommendations for the Cost Enabling Condition of Circularity in Indonesia

- Prioritize fiscal and regulatory enablement of revenue-positive or near-viable interventions (slag valorization, water reuse, industrial symbiosis) in the near term; treat integrated battery recovery and tailings reprocessing as medium-term, while distinguishing battery pre-treatment, which sits at a materially lower capital and waste threshold than final metal extraction and can reach an established export market for black powder, from the post-treatment capacity that should follow it (Section 3.1).
- Introduce disposal levies or landfill charges on recoverable nickel processing residues to distinguish the economic weight of recovery and landfill (Section 3.2.2).
- Ensure that domestically recovered secondary material is not taxed on transactions from which imported primary material is exempt under downstream tax holidays, since the current treatment prices domestic secondary supply above imports and works against building recovery capacity.
- Use public procurement and fiscal incentives to build domestic markets for secondary materials and second-life batteries, reducing the first-mover risk that deters private investment.

3.3.2 Infrastructure

Overview of Best Practices in Circularity Infrastructure

Circularity depends on infrastructure. For nickel, process circularity requires physical infrastructure for water recycling, tailings and slag handling, and energy recovery at mines and processing plants, and benefits from the co-location of complementary facilities. Product circularity requires reverse logistics infrastructure—the networks, collection points, and transport arrangements that bring end-of-life nickel-bearing batteries back into managed systems—together with safe storage and handling capacity for hazardous battery waste, and black mass and hydrometallurgical recovery capacity to extract nickel sulfate for re-entry into the cathode supply chain. Both depend increasingly on digital infrastructure for traceability: data systems, product registries, and instruments such as digital product and battery passports that allow nickel content to be tracked, verified, and matched to secondary users (Section 3.2.1).[315]

The industrial-park model—the organizing unit of Indonesia's nickel processing—is an infrastructural asset for circularity. Eco-industrial parks and industrial symbiosis clusters (Kalundborg in Denmark being the canonical example) use shared infrastructure and co-location so that one facility's by-products, waste heat, and water become another's inputs—precisely the configuration in which nickel slag, HPAL waste heat, and process water could be circulated within parks such as Morowali and Weda Bay.[316]

State of Play of Circularity Infrastructure in Indonesia

Indonesia's circularity infrastructure is uneven and concentrated. On process circularity, industrial parks such as the Morowali and Weda Bay complexes already co-locate mining-adjacent processing at scale, which is a precondition for industrial symbiosis—but that co-location is currently organized around primary processing and shared power and logistics, not around closing material loops, and the parks are simultaneously concentrating environmental risk, including tailings storage pressure and waste volumes that have outpaced safety infrastructure (Section 3.1).[317]

On the product side, reverse logistics and collection infrastructure for end-of-life batteries is nascent. Most formally licensed hazardous waste recycling facilities are concentrated in Java and a few industrial centers, leaving much of the archipelago without accessible processing options and imposing high transport costs and logistical complexity on collection.[318] Collection networks are fragmented, and most end-of-life electronics are handled through informal channels (Section 3.2.2). Digital traceability infrastructure is largely absent: there is no mandatory battery passport or digital product passport system. The Mineral and Coal Information System (*Sistem Informasi Mineral dan Batubara Antar Kementerian/Lembaga,* SIMBARA platform) for mineral production and compliance tracking indicates growing state capacity for digital monitoring that could, in principle, be extended toward circularity.[319]

Gaps, Challenges, and Opportunities

The principal opportunity is to repurpose the industrial park as a deliberate circularity hub: using park licensing, shared infrastructure, and co-location incentives to organize industrial symbiosis (slag and by-product offtake and shared water recycling and waste heat systems). Indonesia's archipelagic geography is the defining challenge for product circularity infrastructure: distributed collection across islands is costly; without policy support, reverse logistics is likely not to extend beyond Java. There is a corresponding opportunity to de-risk and incentivize legally compliant collection and recycling capacity outside the main industrial centers, and to build digital traceability incrementally—starting with EV and industrial batteries, where the number of actors is small enough for enforcement through licensing and registration.[320]

The archipelagic constraint begs the question of whether the recovery chain must be built domestically. Two features of battery recovery economics bear on it. The first is that transport dominates the cost structure: assessments of European operations attribute 30–70% of total recycling cost to transport, because end-of-life batteries require certified containers and specialized handling, and that share rises with distance and where movements cross borders.[321] The second is that recovery strongly depends on scale. Hydrometallurgical processing is profitable only at high throughput, and many European facilities operate at under 10% of capacity for want of returns.[322] Recovery capacity must therefore sit close to where material is retired, and draw on a catchment large enough to fill it.

Considered within Indonesian borders, those requirements are in tension: proximity argues for distribution across the archipelago, and scale argues for concentration. Considered regionally, they are not. The binding constraint on advanced hydrometallurgical recycling in both Indonesia and the Philippines is not technical feasibility but aggregation, since neither generates sufficient volume alone to justify the investment.[323] This finding makes the case for regional circularity corridors and it fits how recovery works, since recovery is a chain, and each link needs something different: collection needs proximity to consumers, dismantling needs trained workers and safety systems, first-stage processing needs ports and industrial land, and refining needs scale, power, and technical skill. No country in the region has the conditions for all of them. Indonesia is strong on the later links and weak on collection.

Collection is the one link that cannot be relocated, since batteries retire where vehicles are used, so Indonesia needs its own collection network regardless. The regional question is not whether Indonesia collects, but where material goes once collected, and a corridor is the division of labor that answers it: Indonesian refining and HPAL capacity absorbing material aggregated across the region, with pre-treatment distributed closer to where batteries retire.[324] What determines whether this works are the licensing, safety classification, and waste movement rules governing reverse flows, which the recycling literature identifies as the candidates for regional streamlining.[325] A regional corridor already exists in the IndoPhil arrangement (Section 3.2.1), built around complementarity in the primary nickel chain, and its scope could be extended to recovery.

A further infrastructure constraint sits on the process side: storage capacity for tailings. After the government declined to permit deep-sea tailings disposal, HPAL operators shifted to land-based filtered (dry-stacked) storage (Section 3.2.2(A)), placing the burden of waste management on physical storage infrastructure that is not yet adequate to the scale of HPAL expansion. Indonesia has commissioned roughly ten HPAL plants in five years, and operations are creating, or planning to create, hundreds of millions of tons of filtered tailings; HPAL generates close to double the tailings of conventional processing.[326] Some Indonesian facilities are larger and store more waste than comparable operations elsewhere with similar rainfall, raising the question of whether dry stacking is being applied beyond its tested limits in a humid, seismically active archipelago.[327] The consequences are already material: a series of filtered-tailings breaches and landslides at major nickel hubs in 2025 and 2026 caused fatalities and, in one February 2026 incident, halted four HPAL plants accounting for around 30% of national HPAL capacity. Storage capacity is therefore a binding infrastructure constraint on a circular nickel value chain, and a direct risk to production continuity.[328]

Recommendations for the Infrastructure Enabling Condition of Circularity in Indonesia

- Make industrial parks circularity hubs by embedding industrial symbiosis requirements and co-location incentives in industrial park licensing, and provide shared circular infrastructure (water recycling, by-product handling, and waste heat networks) as a park-level service.
- Extend compliant battery and e-waste collection beyond Java through a combination of regulatory and fiscal measures, licensing intermediate aggregation and sorting points that allow material to be consolidated before long-haul transport, and recognizing that the barrier extends beyond the archipelagic geography to the permitting and licensed handler requirements (Section 3.2.2).
- Treat land-based filtered tailings storage as critical circular infrastructure: require forward storage capacity planning and the identification of suitable land as a condition of HPAL expansion, coordinated with the tailings safety standards (Section 3.1.4).
- Phase digital traceability. Begin mandatory traceability with EV and industrial batteries, leveraging existing licensing and the digital monitoring capacity demonstrated by platforms such as SIMBARA, then expand.
- Plan for regional circularity corridors and hubs. Assess which links in the recovery chain Indonesia is best placed to host, rather than attempting to build the whole chain domestically at sub-viable scale. Prioritize processing and refining hubs, where domestic conditions are strongest, and pursue harmonized safety classification, transport licensing, and border requirements to

allow material to move along a corridor from collection and pre-treatment points, in Indonesia and elsewhere in the region, to those hubs (Section 3.2.1). This recommendation can be advanced through the ASEAN Minerals Cooperation Action Plan 2026–2030 (AMCAP-IV) and the existing IndoPhil Nickel Corridor, whose current scope covers the primary chain and should be extended to recovery, secondary materials, and reverse flows.

3.3.3 Skills and Labor

Overview of Best Practices in Circularity Skills and Labor Considerations

Circularity changes the work as well as the technology. In the nickel value chain, operating filtered tailings facilities safely, running hydrometallurgical nickel and black mass recovery, characterizing and reprocessing nickel tailings and slag, and managing battery reverse logistics all require skill sets that differ from those of conventional nickel extraction and smelting. Best practice therefore pairs circular economy policy with capacity building, including technical and vocational training, standards and certification for new occupations, and worker up- and re-skilling programs developed with industry. Circular employment is often informal and precarious, particularly in the Global South, so a just transition approach must address job quality, worker safety, and the inclusion of informal workers.[329]

State of Play of Circularity Skills and Labor Considerations in Indonesia

Worker safety is the most acute labor dimension of circularity in Indonesia's nickel sector today. The rapid expansion of HPAL and the associated growth in tailings volumes have been linked to repeated landslides and tailings facility failures at and around mine and processing sites; more broadly, Indonesia's nickel sector recorded on the order of 90 workplace accidents with dozens of fatalities and scores of injuries over the eight years to 2023, including waste pool explosions and furnace fires at major parks, underscoring why waste-reducing circular practices have a direct safety impact.[330] On the product side, end-of-life batteries and electronics are largely handled through informal value chains of scrap dealers, collectors, and small-scale processors, raising safety concerns from exposure to hazardous materials.[331]

On formal skills development, Indonesia's circular economy roadmap recognizes capacity building. Other studies have generated estimates of job-creation potential in circular activities, but dedicated circular economy skills programs, occupational standards, and certification for circular roles in the nickel value chain remain limited in Indonesia.[332]

Gaps, Challenges, and Opportunities of Circularity Skills and Labor Considerations in Indonesia

The defining gaps are knowledge and safety. Operating circular technologies safely in Indonesia's seismic, high-rainfall context demands specialized engineering and monitoring skills that are in short supply (Section 3.1), and the dominance of informal waste handling creates a population of workers exposed to hazardous materials without protection or training. The opportunity is to treat skills as part of the enabling environment, linking the technical training capacity discussed in Section 3.1.1 (national research institutions, international "train the trainer" partnerships) to the labor base, developing occupational standards for tailings management and battery handling, and designing formalization pathways that bring informal workers into safer, certified roles. The central challenge is that formalization must be made more economically attractive than the informal status quo, which requires combining regulation and enforcement with incentives.

Recommendations for the Skills and Labor Enabling Conditions of Circularity in Indonesia

- Develop safety-critical skills, occupational standards, training, and certification for tailings facility operation and monitoring and for hazardous battery handling, tied to the technical standards recommended in Sections 3.1 and 3.2.2.

- Design pathways to bring informal e-waste and battery workers into formal collection and recovery systems with safety protections, pairing enforcement with compliance incentives.
- Establish circular economy training and re-skilling programs with industry, leveraging international technology transfer partnerships to target high-potential occupations.

3.4 Policy Toolkit: Summary of Policy Recommendations

Table 3 summarizes policy recommendations advanced throughout Section 3 to integrate circular economy principles and practices into nickel value chains in Indonesia. Recommended policy measures are grouped by enabling condition and by topic.

These measures are designed to operate as a package rather than as a menu to pick and choose. Several are ineffective in isolation because they presuppose conditions that other measures establish. For instance, a disposal levy changes behavior only where a recovery route exists and residues have been characterized well enough to establish that they are recoverable. Mutual recognition of classifications delivers market access only once domestic end-of-waste criteria have been set. A second-life requirement presumes a grading method. Adopted singly, the instruments that are easiest to introduce are also the ones most likely to underperform, because a price signal or a reporting duty without the surrounding conditions shifts cost and paperwork rather than practice.

The priority levels in the Policy Toolkit reflect that dependency rather than relative importance. Measures assigned high priority concentrate on specification, disclosure, and classification: they are the conditions on which other measures depend, not necessarily the measures with the largest effect. Those assigned medium priority, including regional integrated battery recovery, tailings reprocessing, and second-life markets, depend on volumes, data, and institutional capacity that do not yet exist.

Table 3. Policy toolkit. Summary of policy recommendations

Enabling condition	Topic	Policy measure	Priority level	Discussed in
Technical	Research capacity	Designate a national institution for research in critical minerals and circularity	High	3.1.1 (A) 3.1.4 (A)
	Technology transfer	Condition foreign technology partnerships on domestic capacity building	High	3.1.1 (A) 3.1.4 (A)
	Tailings safety	Define a design basis for filtered tailings in Indonesian conditions, including wet-weather placement zones	High	3.1.3 (A) 3.1.4 (A)
	Characterization	Extend electrical resistivity tomography (ERT) from ore to waste monitoring	Medium	3.1.2 (A) 3.1.4 (A)
		Define slag composition ranges and a repeatable test procedure against construction product specifications	High	3.1.3 (A) 3.1.4 (A)
	Grading	Develop a pack-level state-of-health assessment procedure and the laboratory capability to apply it	High	3.1.3 (B) 3.1.4 (B)
	Waste prevention	Support advanced geometallurgy and bulk ore sorting	Medium	3.1.1 (A) 3.1.4 (A)

continued...

Enabling condition	Topic	Policy measure	Priority level	Discussed in
Policy – Process circularity	Roadmap	Add mining and processing to the National Circular Economy Roadmap, with targets and assigned agencies	High	3.2.1 3.2.2 (A)
	Classification	Set end-of-waste criteria for nickel residues beyond slag	High	3.2.1 (A) 3.2.2 (A)
		Review classifications periodically as technologies and markets change	High	3.2.1 (A) 3.2.2 (A)
		Pursue ASEAN mutual recognition of waste and by-product classifications	Medium	3.2.1 (C) 3.2.2 (A)
	Tailings management	Codify the halt on new deep-sea disposal permits	High	3.2.1 (A) 3.2.2 (A)
		Issue tailings engineering standards: seismic safety factors, setbacks, and consequence-based design	High	3.2.1 (A) 3.2.2 (A)
		Coordinate HPAL expansion approvals against storage and carrying capacity	High	3.2.1 (A) 3.2.2 (A)
	Tailings reprocessing	Extend the gold tailings reprocessing study trigger and conditions to nickel	High	3.2.1 (A) 3.2.2 (A)
		Specify tailings characterization methodology, parameters, and sampling frequency	High	3.2.1 (A) 3.2.2 (A)
		Exempt or fast-track tailings research samples and pilot volumes from full B3 permitting	High	3.2.1 (A) 3.2.2 (A)
		Aggregate tailings data into a public national inventory	High	3.2.1 (A) 3.2.2 (A)
		Replace self-assessed utilization tests with defined criteria and independent verification	Medium	3.2.1 (A) 3.2.2 (A)
	Slag and symbiosis	Allow reuse of non-B3 residues beyond the generating operator's concession	High	3.2.1 (A) 3.2.2 (A)
		Incentivize co-location of processors and downstream users in industrial parks	High	3.2.1 (A) 3.2.2 (A) 3.3.2
	Landfilling	Establish a waste hierarchy placing disposal last for recoverable residues	High	3.2.1 (A) 3.2.2 (A)

continued...

Enabling condition	Topic	Policy measure	Priority level	Discussed in
	Post-mining	Make guarantee fund deposit a precondition for RKAB approval	High	3.2.1 (A) 3.2.2 (A)
		Anchor fund values to independent restoration cost estimates	High	3.2.1 (A) 3.2.2 (A)
		Require early assessment of beneficial post-mining land uses	High	3.2.1 (A) 3.2.2 (A)
		Tighten the definition of reclamation and narrow alternative designations	High	3.2.1 (A) 3.2.2 (A)
		Establish a guarantee fund for processing and refining post-operation obligations	Medium	3.2.1 (A) 3.2.2 (A)
	Water	Require site water management plans and public reporting of consumption and reuse	High	3.2.1 (A) 3.2.2 (A)
	Energy	Extend energy audits to cover recoverable process heat	High	3.2.1 (A) 3.2.2 (A)
		Fast-track environmental review for circularity retrofits passing a benefit screen	High	3.2.1 (A) 3.2.2 (A)
		Make energy recovery a permitting expectation for new facilities	Medium	3.2.1 (A) 3.2.2 (A)
Policy – Product circularity	Battery regulation	Issue a battery circularity package translating the roadmap into operational rules	High	3.2.1 (B) 3.2.2 (B)
		Define covered battery categories and match obligations to risk	High	3.2.1 (B) 3.2.2 (B)
	EPR	Establish battery-specific EPR	High	3.2.1 (B) 3.2.2 (B)
		Make producers responsible for take-back, financing, and verified treatment	High	3.2.1 (B) 3.2.2 (B)
		Use GR 27/2020 and Permen LHK 6/2021 as the compliance backbone, with proportionate obligations	High	3.2.1 (B) 3.2.2 (B)
		Introduce tiered handling rules by battery condition, chemistry, and risk	High	3.2.1 (B) 3.2.2 (B)
		Introduce eco-modulated fees rewarding circular design	Medium	3.2.1 (B) 3.2.2 (B)
		Accredit and audit producer responsibility organizations; publish fees and tonnages	Medium	3.2.1 (B) 3.2.2 (B)

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Enabling condition	Topic	Policy measure	Priority level	Discussed in
	Producer ownership	Remove legal obstacles: clarify that a producer retaining battery ownership remains the waste holder	Medium	3.2.1 (B) 3.2.2 (B)
		Sequence EPR first, with defined thresholds for moving to producer ownership	Medium	3.2.1 (B) 3.2.2 (B)
		Strengthen battery swapping by recognizing separate battery and vehicle ownership in registration and tax treatment	Medium	3.2.1 (B) 3.2.2 (B)
	Design	Extend mandatory SNI standards beyond primary batteries	High	3.2.1 (B) 3.2.2 (B)
		Reward verified take-back in Green Industry certification	High	3.2.1 (B) 3.2.2 (B)
		Add phased circularity requirements to SNI standards	Medium	3.2.1 (B) 3.2.2 (B)
	Traceability	Introduce phased labeling and digital battery passport requirements	Medium	3.2.1 (B) 3.2.2 (B)
	Targets and standards	Add recovery-efficiency performance standards to recycling permits	High	3.2.1 (B) 3.2.2 (B)
		Create a tariff classification for used batteries	High	3.2.1 (B) 3.2.2 (B)
		Set phased collection and recovery targets; count verified repurposing	High	3.2.1 (B) 3.2.2 (B)
		Introduce minimum recycled-content requirements, phased by chemistry	Medium	3.2.1 (B) 3.2.2 (B)
		Adopt quality standards for secondary materials and second-life use	Medium	3.2.1 (B) 3.2.2 (B)
	Sequencing	Begin with collection, storage, and pre-treatment; stage extraction later	High	3.1.4 (B) 3.2.2 (B)
		Clarify state and private roles across the recovery chain	High	3.1.4 (B) 3.2.2 (B)
		Secure external market access for black powder	Medium	3.1.4 (B) 3.2.2 (B)
	Second-life market	Require second-life suitability assessment before recycling is authorized	High	3.2.1 (B) 3.2.2 (B)
		Build demand for secondary materials and second-life batteries through public procurement preferences and fiscal incentives	Medium	3.2.1 (B) 3.2.2 (B)
		Establish testing and certification for repurposed batteries	High	3.2.1 (B) 3.2.2 (B)

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Enabling condition	Topic	Policy measure	Priority level	Discussed in
Governance	Enforcement	Set fixed inspection timelines and a published assessment framework	High	3.2.1 (C) 3.2.2 (C)
	Disclosure	Mandate public disclosure of facilities, assessments, closure plans, and assurance	High	3.2.1 (C) 3.2.2 (C)
	Coordination	Designate a single institutional home for circular economy policy and ensure coordination among different government entities	High	3.2.1 (C) 3.2.2 (C)
	Accountability	Introduce environmental carve-outs to limited liability; assign board-level responsibility	Medium	3.2.1 (C) 3.2.2 (C)
Costs	Sequencing	Enable revenue-positive measures now; de-risk capital-intensive ones later	High	3.3.1
	Fiscal neutrality	Remove the tax disadvantage on domestic secondary material versus imports	High	3.3.1
	Pricing	Introduce a disposal levy on residues with recoverable value	High	3.2.1 (A) 3.2.2 (A)
Infrastructure	Industrial parks	Embed symbiosis requirements and shared circular infrastructure in park licensing	High	3.2.2 (A) 3.3.2
	Tailings storage	Require forward storage planning as a condition of HPAL expansion	High	3.3.2
	Collection	Extend compliant collection beyond Java; license intermediate aggregation points	Medium	3.3.2
	Traceability systems	Build the digital tracking platform, leveraging SIMBARA capacity	Medium	3.3.2
	Regional corridors	Prioritize processing hubs; pursue harmonized classification and transport rules	Medium	3.3.2
Skills and labor	Safety	Certify tailings operation and hazardous battery handling roles	High	3.3.3
	Formalization	Bring informal collection workers into formal systems with protections	Medium	3.3.3
	Training	Build circular economy training programs with industry partners and formal education	Medium	3.3.3

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