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Critical Minerals in Southeast Asia: From Extraction-Led Growth to Circular Supply Chains

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9

ABOUT THE SERIES

This policy brief is a series of research documents summarizing the knowledge of area contextualized to Southeast Asia and Malaysia, in particular from ongoing research work by the Center for Technology, Strategy & Sustainability (CTSS) at the Asia School of Business. The author of this issue is **Angela Tritto, Assistant Professor at the Institute of Asian Studies, The University of Brunei Darussalam**

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Executive Summary

- Southeast Asia is emerging as a critical node in global supply chains for energy transition minerals, with governments prioritizing mining, processing, and electric vehicle (EV) industrialization. However, policy frameworks remain heavily focused on upstream and midstream activities, with limited attention to recycling, reuse, and material substitution.

- This policy brief examines Malaysia, Indonesia, the Philippines, Vietnam, and Thailand, and finds a consistent pattern: while all have introduced elements of circular economy or e-waste policy, these remain fragmented, weakly enforced, and poorly integrated into mineral and industrial strategies. Circularity is generally treated as a waste management issue rather than a strategic component of supply security.

- Indonesia and Malaysia illustrate the clearest imbalance, combining strong industrial policy with limited downstream recovery systems. The Philippines and Thailand lack comprehensive regulatory frameworks, while Vietnam shows emerging alignment through Extended Producer Responsibility (EPR) but faces implementation challenges. Across the region, informal recycling, weak infrastructure, and regulatory gaps constrain material recovery.

- As a result, Southeast Asia risks reinforcing a linear extractive model, missing opportunities to recover valuable materials, reduce environmental impacts, and strengthen long-term supply resilience.

- The brief argues that a more balanced strategy is needed—one that integrates circular economy principles, strengthens regulatory frameworks, invests in recycling infrastructure, and supports technological innovation. It also highlights the role of economic diplomacy in enabling technological leapfrogging and higher-value participation in global supply chains.

Introduction

Despite their name, rare earth elements are not geologically rare (Klinger, 2018). More broadly, the classification of certain resources as "critical minerals" reflects strategic economic and geopolitical considerations rather than intrinsic scarcity. Over the past decade, governments have increasingly framed minerals such as nickel, lithium, cobalt, and rare earth elements as essential for the energy transition, advanced manufacturing, and digital technologies. This has triggered a global effort to secure access to mineral resources and expand domestic processing capacity.

Southeast Asia has emerged as a key arena in this process. Countries across the region possess significant deposits of minerals required for low-carbon technologies, including nickel in Indonesia and the Philippines, and rare earth elements (REE) in Myanmar, Vietnam, and Malaysia. Recently, governments have adopted policies to capture greater economic value from these resources. These strategies typically emphasize export restrictions, downstream industrialization, and incentives to attract foreign investment into mineral processing industries. Indonesia's nickel sector provides a prominent example, having attracted large-scale foreign investment—particularly from Chinese firms—into smelting and refining, transforming the country into the world's largest nickel producer (Tritto, 2023).

The rapid expansion of mineral extraction and processing has also generated significant environmental, social, and governance challenges. Mining activities across the region have been associated with deforestation, habitat loss, community displacement, and labor concerns. Overall, the growing demand for critical minerals raises broader questions about the sustainability of the energy transition itself, as narratives of decarbonization often obscure the extractive costs associated with large-scale material production (Tritto, 2026).

Global policy debates increasingly highlight alternative pathways to securing critical mineral supply. These include technological innovation, recycling, and material substitution, which can reduce reliance on primary extraction while mitigating supply chain risks (Crebo-Rediker & Khan, 2026). Despite these developments, policy responses in Southeast Asia remain largely focused on expanding mineral supply.

This policy brief examines how governments in Southeast Asia are approaching the challenge of critical minerals and asks whether current strategies sufficiently incorporate these alternative pathways. It reviews policies across Malaysia, Indonesia, the Philippines, Singapore, Vietnam, and Thailand and finds that, while mineral and industrial strategies are becoming more sophisticated, circular economy approaches and technological alternatives remain fragmented and weakly integrated into policy frameworks.

The brief concludes by outlining policy options to balance mineral development with environmental sustainability, technological innovation, and long-term resource security.

Critical Minerals Reserves, Production, and Strategies in Southeast Asia

Southeast Asia plays a significant role in global mineral supply chains. Indonesia alone produces roughly 60% of the global nickel supply (see Figure 1), followed by the Philippines (9%), the second-largest world producer, with much more limited domestic processing. Indonesia's share of global cobalt production has risen to around 10%, driven by the government's strong ambitions to develop EV battery supply chains. Myanmar has emerged as a major producer of heavy rare earth elements, accounting for about 9% of the world's total, which come from deposits in the country's northern Kachin State, near the border with China. Much of Myanmar's production tends to contain higher concentrations of heavy rare earth elements (HREEs) [1] such as dysprosium and terbium, which are essential for high-performance permanent magnets used in electric vehicles, wind turbines, and other advanced technologies (International Energy Agency, 2023; U.S. Geological Survey, 2025). Most of Myanmar's rare earth production is exported to China for processing, reflecting the country's limited domestic refining capacity and China's dominance in downstream rare earth separation and magnet manufacturing.

Vietnam hosts some of the largest light rare earth reserves outside China, particularly in the Dong Pao region in the North of the country, but production remains very limited. Notably, it has the second-largest reserves of tungsten, and its strategic plant, operated by Vietnamese Masan High-Tech Materials, accounts for only 4.2% of global production (Singh, 2025). Thailand has a mix of light and heavy rare earth elements (REE) and, while still modest, its production has been increasing in recent years. It is worth noting that there is no commercial mining of rare earth minerals in Thailand; hence, most of its production is by 'beneficiation' whereby Thai companies import mined products and process them to extract ores containing rare earth-bearing minerals (Leenoi, 2025). Finally, the region collectively accounts for 45% of global tin production, with Myanmar and Indonesia as the largest producers (U.S. Geological Survey, 2025).

Southeast Asia’s position is also becoming increasingly significant in midstream and downstream activities. For instance, Malaysia and Laos are second and third globally in the export of rare-earth compounds, representing 20% and 14% of the world total, respectively (Leenoi, 2025).

[1] See the Appendix for a list of Heavy and Light REE and their usage.

Malaysia's production is supported by foreign investment from Lynas Rare Earths, which established its facility in 2012, and since 2014, the country has been the world's leading exporter of Rare Earth Oxides (REOs; ibid.). Indonesia is by far the largest refiner of nickel, having since 2018 attracted investments from Chinese, Japanese, and Korean companies in High-Pressure-Acid-Leaching (HPAL) facilities to refine nickel for EV battery manufacturing (Tritto, 2023). Vietnam is instead the world's third-largest producer of magnets, thanks to the production of Japanese Shin-Etsu Chemical. The production of powerful permanent magnets is a key downstream activity for the manufacture of components for EV motors, wind turbines, and smartphones (Leenoi, 2025).

These developments are not accidental. Across Southeast Asia, governments have increasingly used mineral policy to capture more value domestically through export controls, refining mandates, investment incentives, and industrial partnerships. However, they are doing so in different ways (see Table 1). Several countries have passed new mineral legislation and introduced incentives for related industries in the last two years.

Indonesia had a head start over ten years ago and now has the most interventionist model, using export bans and local content requirements to attract foreign investment in refining and battery manufacturing. Malaysia is pursuing a similar strategy for rare earths, using a raw export ban to encourage domestic processing and potential downstream magnet industries. Vietnam is building a stronger legal basis for strategic mineral management and processing, but its industrial capacity remains limited. A major reform was the 2024 Law on Geology and Minerals, which liberalized the mining sector, introduced classifications of mineral resources, and established competitive auctions for mining rights, with exceptions for national strategic projects (Singh, 2025). In 2025, a green taxonomy and further controls on raw mineral exports were introduced. The Philippines is still caught between upstream export dependence and ambitions for value addition, with 2025 reforms under the RA12253 focused more on fiscal governance related to royalties. Thailand, by contrast, relies more on investment promotion for EV and battery manufacturing than on hard mining-to-processing controls.

Table 1. Key domestic policies across selected Southeast Asian countries by value chain segments

Country	Upstream (Extraction)	Midstream (Processing & Refining)	Downstream (Manufacturing & Use)
Indonesia	Export bans on raw minerals (nickel, bauxite, copper); licensing tied to domestic value-add; strong state control of mining	Mandatory domestic smelting; rapid expansion of refining capacity (nickel, copper); large-scale foreign investment (esp. China)	Active development of EV battery ecosystem; integration into global EV supply chains; industrial policy targeting battery manufacturing
Malaysia	Emerging rare earth mining (IAC deposits); ban on export of unprocessed rare earths; resource governance is still developing	Strong push for domestic REE processing; active attraction of foreign technology and investment; existing processing hub (e.g., Lynas)	Ambitions in magnet production and EV-related industries; circular economy policies promoting recycling and reduced material intensity
Philippines	Major nickel producer; continued export of raw ore; debate on export bans; mining fiscal reforms (RA 12253, 2025)	Limited refining capacity; early-stage investments; government support for R&D in metallurgy and mineral processing	Downstream ambitions in EV and clean-tech sectors (RA11697, 2022), but limited industrial policy tools; mostly aspirational
Thailand	Limited state intervention in mining; investment promotion for extraction projects via BOI; regulatory but not restrictive approach	Some support for mineral processing (BOI incentives), but no strong national refining push	Strong focus on EV and battery manufacturing; major incentives for EV industry (EV 3.5 package); downstream-led industrial strategy
Vietnam	New Law on Geology and Minerals (2024/2025); stronger control over strategic minerals; large rare earth reserves, but low production	Policy emphasis on improving mineral processing; early-stage development of refining capabilities; focus on strategic minerals (REEs)	Emerging ambition to enter REE supply chains; limited domestic capacity in advanced processing and manufacturing

Sources: IEA, 2021; USGS, 2025; Indonesia – MEMR 2024a;2024b; Indonesia Investment Coordinating Board, 2024. Malaysia – MIDA, 2024a, 2024b; IEA, 2024; Philippines – Las Piñas, 2025; Thailand: TBOI 2025, TBOI, 2024; Rajah & Tann Asia, 2025.

The above domestic policies and blueprints aim to expand extraction and domestic processing, and to create vertically integrated value chains to support the development of key technology industries. Indonesia, Malaysia, and Vietnam have implemented export restrictions for raw minerals and varying degrees of local content requirements. In midstream and downstream activities, the role of foreign investments that bring technologies and capital is essential.

This is why several countries have already signed agreements and MOUs related to mineral development. Minerals are now part of geopolitical considerations; hence, there is a strong resurgence of the U.S. presence in the region to divert some of these minerals' supply away from China. Some have called this a “Pax Silica” – the strategy to link semiconductor supply chains, artificial intelligence infrastructure, and mineral deals into a single strategic ecosystem (Klinger-Vidra et al., 2025).

Table 2 summarizes the main agreements and MOUs on critical minerals signaling alignment for each Southeast Asian country. Vietnam signed a Comprehensive Strategic Partnership (CSP) with the U.S. in 2023, which mentions collaborations in semiconductor development and critical minerals (U.S. State Department, 2025). Recently, Vietnam also agreed to strengthen relations with the EU to foster the development of critical minerals (Guarascio, 2026). Japan is also a longstanding partner, with a center for technology transfer on rare-earth elements established since 2012 (Fuyuno, 2012). Scholars see this as the development of strategic autonomy (Klinger-Vidra et al., 2025) and as pursuing national interests by diversifying partnerships to remain non-aligned or multi-aligned. Other countries adopt similar strategies. In 2025, Malaysia and Thailand have also signed deals to strengthen cooperation with the U.S. in critical minerals supply chains (MFA, 2025; White House, 2025a, 2025b). The Philippines followed suit with 11 other countries in 2026 (Embassy of the Republic of the Philippines, 2026), and Indonesia also recently granted greater access to the U.S. for its energy and minerals (Republic of Indonesia, 2026).

Table 2. Key agreements related to critical minerals in selected Southeast Asian countries.

Country	Partner	Mineral Focus	Type of Agreement	Value Chain Focus	Notes
Vietnam	United States	Rare earths / critical minerals	CSP (2023)	Upstream + Midstream	Cooperation on mining, processing, and supply chain diversification
	European Union	Critical minerals	Agreement	All	Boost trade and investment in critical minerals, semiconductors, and infrastructure
	Japan	Rare earths	Bilateral cooperation	Upstream + Midstream	Technology transfer, processing center in Hanoi
Indonesia	United States	Nickel (battery materials)	Bilateral cooperation	Midstream + Downstream	Aimed at integrating Indonesia into U.S. EV supply chains
	China	Nickel	Industrial cooperation / joint ventures	Midstream + Downstream	Smelters and battery materials (Morowali, Weda Bay)
Philippines	United States	Critical Minerals	MOU (2026)	All	Focus on supply chain diversification and investment
	Japan	Nickel, cobalt	MOC, 2023; Project finance / long-term supply arrangement	Upstream + + midstream	Longstanding investment and supply agreement, exploration, development, operation, sustainable mining, and R&D regarding critical minerals
Malaysia	Australia	Rare earths	Industrial agreement (Lynas)	Midstream	Processing hub for REEs
	Japan	Rare earths	Memorandum of Cooperation with JOGMEC MOC with ECERDC (2025)	Midstream + knowledge/technology cooperation	Supply chain diversification
	United States	Critical minerals	MOU (2025)	All	Promote trade and investment in resource exploration, extraction, processing, refining, and recycling and recovery
Thailand	United States	Critical minerals	MOU (2025)	All	

Like Vietnam, other Southeast Asian countries are diversifying their partnerships via cooperation agreements for hands-on industrial development projects. Indonesia has strong industrial partnerships with Chinese, Japanese, and Korean companies to develop its nickel industry. Malaysia has a longstanding industrial partnership with Australian Lynas, and the Japan Organization for Metals and Energy Security (JOGMEC) has recently signed a Memorandum of Cooperation (MOC) with Japan to develop rare earths and other mineral resources (JOGMEC, 2025). Japanese Sumitomo's early investment in the Filipino Taganito HPAL Nickel Corporation (THPAL), supported by a Japan Bank for International Cooperation loan (JBIC, 2011), now complements a larger mineral partnership between the Ministry of Economy, Trade and Industry (METI) and the Department of Environment and Natural Resources (DENR) of the Philippines, as an MOC was signed in 2023 to facilitate sustainable development in the mining and mineral resources (METI, 2023). While countries differ in how they structure both domestic policies and external partnerships, a common pattern emerges. Across the region, mineral governance is increasingly oriented toward expanding extraction, building domestic processing capacity, and integrating into global manufacturing supply chains. By contrast, comparatively limited attention is given to alternative pathways such as recycling, material substitution, and demand reduction. Although references to sustainability and circular economy principles are present in some policy frameworks, they are rarely central to industrial or mineral strategy. This imbalance forms the basis for the analysis in the following sections.

The Costs of Supply-Focused Mineral Development

While countries are increasingly enterprising in launching mineral statecraft and diplomacy initiatives, they often neglect the downsides of these strategies. Taking Indonesia as an example, the country is now the world's largest nickel producer, continuously ramping up its captive coal power plant fleet to meet the demand of its energy-intensive smelter plants (Setiawan, 2025).

As a result, Indonesia ranks first in Southeast Asia and fifth in the Asia-Pacific region in carbon emissions (Fernández, 2025). An earlier study showed that this increase in coal power would result in at least 25,000 premature deaths per year by 2030 (Koplitz et al., 2017). Attempts to decarbonize the industry have been slow or equally destructive, as in the case of the Mentarang Induk Hydroelectric Project (MIHEP), -

-a $2.6 billion, 1.375 GW hydropower plant in North Kalimantan to power the large green industrial park currently hosting a bauxite smelter, which is cutting pristine forests and displacing indigenous communities along the Kayan river (Naem, 2025). Nickel mining is also connected to large-scale deforestation, including in protected high-carbon forests (Brown and Harris, 2024), and runoff from mining sites has damaged coastal and marine ecosystems critical to local livelihoods (Tritto, 2026). The social toll is equally grim. The naming of ‘blood nickel’ came after investigations over several fatal industrial incidents, and suicides linked to harsh and unsafe, exploitative conditions (Collins et al., 2024). Intimidations, arrests, and protests over labor conditions and land rights are also on the rise, along with criminal activities linked to illegal mining (Church and Crawford, 2020; Adinda, 2023; Colantoni, 2024).

Myanmar has also raised serious environmental and governance concerns about illegalities and criminal activities associated with rare earth mining. Mining operations have expanded rapidly in recent years, often under conditions of weak regulatory oversight and political instability, raising questions about the long-term sustainability of these supply chains (International Energy Agency, 2023). Yet these largely unregulated mines, controlled mostly by Chinese companies, are an essential source of heavy rare earth elements (HREE), used for magnets in electric vehicles (EV) and wind turbines globally (Global Witness, 2024). They are mostly mined in Kaching, an area under the military junta's control, and satellite images over just two years showed a 40% increase in mining sites (ibid.). Other areas controlled by ethnic armed organizations (EAOs), such as the Kaching Independence Organization (KIO), also exhibit similar dynamics (ibid.). Ion-adsorption clay extraction typically involves chemical leaching techniques that can generate significant environmental and health impacts if not properly managed (Chen et al., 2023). In conflict-ridden borderlands, where EAOs use mineral profits to support their resistance against the military government, significant environmental damage and contamination of water and soil are threatening the livelihood of communities already living in a perilous state and creating “sacrifice zones” that serve an energy transition that seems all but just (Meehan et al., 2025).

In countries like Malaysia and the Philippines, protesters have also long fought against mining. In Malaysia, since 2012, environmental groups like Save Malaysia Stop Lynas (SMSL) and Himpunan Hijau have protested the Lynas Rare Earths refinery in Kuantan, Pahang, over fears of radioactive contamination, environmental damage, and waste management safety (Associated Press, 2012).

Yet the protests were largely overshadowed by the political upheavals and other high-profile crises in Malaysia, and strong government incentives continued to support the plant's operation (Lim and Wong, 2024). The Philippines shut 23 nickel mines back in 2017 in a clampdown against environmental degradation and following protests by indigenous people (Reuters, 2017). But protests have recently returned once again against the rising environmental destruction, water contamination, and human rights abuses affecting indigenous communities and local livelihoods around mine sites in Palawan and Zambales, where projects proceeded without proper consent or oversight, leading to deforestation and health issues (Amnesty International, 2025). The Philippine case shows that either there is a memory loss regarding minerals or priorities fall to industrial goals. This mining resurgence raises critical questions about emissions, environmental protection, and rising inequality. Too few countries are considering alternatives, even though research and analysts have increasingly pointed out their existence.

Alternative Pathways: Innovation, Recycling and Substitution

While current policy approaches in Southeast Asia are largely focused on expanding mineral supply, a growing body of research highlights alternative pathways to securing critical materials. These include recycling and circular economy strategies, improvements in material efficiency, and technological substitution, all of which can reduce dependence on primary extraction. This section reviews these alternative pathways and assesses their relevance for the region.

RECYCLING AND CIRCULAR ECONOMY

Recycling and reuse represent key pathways to reduce reliance on primary mineral extraction. Secondary supply from end-of-life products—particularly batteries and electronic waste—could play an increasingly important role in meeting future demand for critical minerals. In the near term, however, contributions remain limited due to the relatively small volume of end-of-life clean energy technologies currently available. As a result, primary extraction is expected to remain the dominant source of supply over the coming decade.

Estimates of recycling potential vary significantly across studies. Scenario-based projections suggest that recycled supply could meet around 10–30% of demand for most minerals by 2040 (International Energy Agency, 2023:184), while technical studies indicate that long-term potential could be substantially higher under more ambitious policy and technological assumptions.

For instance, closed-loop recycling potential (CLRP) [2} is expected to remain below 10% in the current decade but could rise to 20%-71% by 2040–2050, depending on battery technologies and policy support (Xu et al., 2020).

Recycling can also significantly reduce material demand and environmental impacts. Studies show that battery recycling and reuse could reduce demand for lithium, cobalt, and nickel by large margins over time (respectively, 67%, 96%, and 93%), while also lowering lifecycle carbon emissions (by 36.0-37.9%) (Jiang et al., 2025). However, the benefits depend on the recycling methods used. Conventional hydrometallurgical and pyrometallurgical processes can be energy-intensive and environmentally burdensome, underscoring the need to develop more cost-effective and environmentally efficient approaches, such as direct recycling (Tao et al., 2021). Table 3 shows that several minerals—particularly cobalt, lithium, and copper—could increasingly be supplied through secondary sources over the long term. However, recycling potential remains more limited for minerals such as rare earth elements, where technical and economic barriers persist. So far, the most comprehensive policy framework for mineral recycling and the circular economy has been developed by the European Union. Initially, targets were too low and inadequately articulated to promote comprehensive recycling (Church and Wuennenber, 2019), so these were recently raised and redefined according to three main time horizons to reach 95% for cobalt, copper, lead, and nickel, and 80% for lithium by 2031 (European Commission, 2025).

Table 3. Recycling potential and substitution pathways for selected critical minerals.

Mineral	Recycling potential (%)	Key substitution	Notes	Key sources
Lithium	10–40% (long-term)	Sodium-ion batteries	Recycling is limited short-term due to low end-of-life volumes; improves after	IEA, (2021); (Xu et al., 2021)
Nickel	10–30%	LFP batteries (reduces demand)	Mature recycling in stainless steel; growing role in batteries	IEA (2021); (Xu et al., 2021)
Cobalt	20–60%	LFP batteries; cobalt-free chemistries	High recycling potential due to economic value	Church, and Wuennernberg, (2019); IEA (2023b); Xu et al. (2021);
Rare earths	5–20% (low–moderate)	Magnet innovation, reduced dysprosium use	Technically difficult to recycle; limited infrastructure	IEA (2021); Ragonnaud (2023)
Graphite	10–30% (emerging)	Silicon anodes; alternative battery chemistries	Recycling technologies still developing	IEA (2021); Xu et al. (2021)
Copper	30–50% (already high)	Material efficiency	One of the most recycled metals globally	Hund et al. (2020); Graedel et al. (2015)

[2] i.e., the percentage of battery material demand that can be met with secondary material from battery recycling.

Investment trends suggest growing momentum behind circular supply chains (see Figure 2). Battery recycling has become a major focus of venture capital funding globally, with significant activity in the United States, China, and Europe. New recycling facilities are being developed, and technological innovation is accelerating, including in Southeast Asia. In 2021, Singapore-based Green Li-ion launched the first battery recycling plant in the ASEAN region. Recently, India's Attero also announced the opening of a recycling facility in Indonesia by 2024 (Saxena, 2022), while Contemporary Amperex Technology Co. Limited (CATL) from China has partnered with Indonesia's Aneka Tambang (ANTAM) and Indonesia's Battery Corporation for the Indonesia Battery Integration Project (Contemporary Amperex Technology Co., Limited, 2025). The project is valued at approximately US$6 billion, and the facilities are expected to process 20,000 tons of used batteries annually, with metal recovery rates reaching 95% (CATL, 2025).

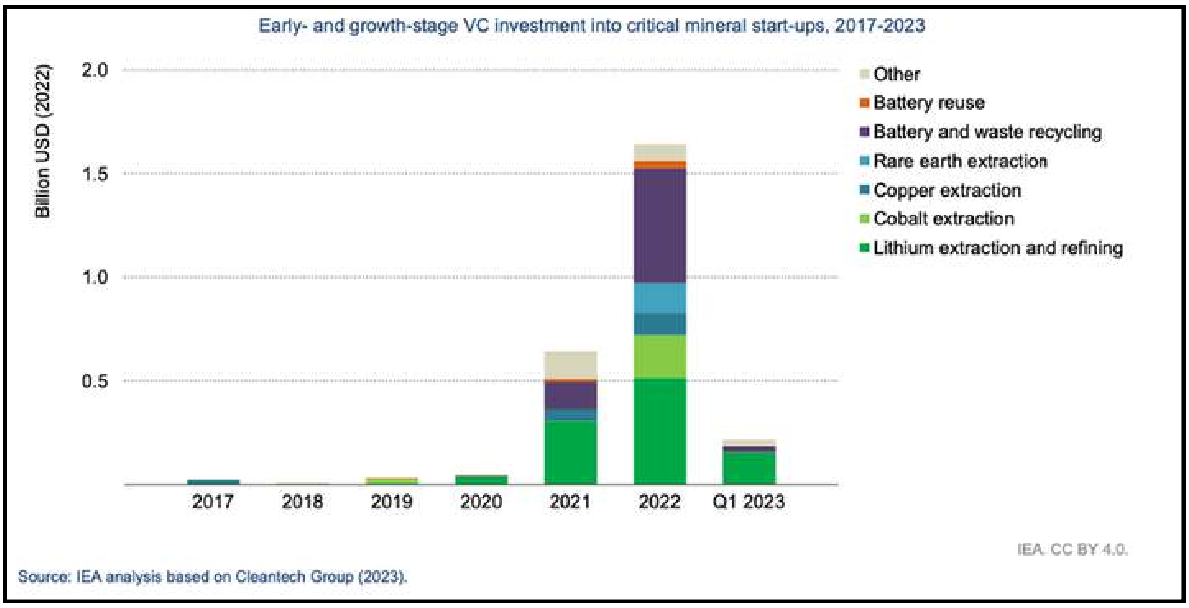

Figure 2. Early- and growth-stage VC investments in critical minerals start-ups. 2017 -2023. Source: IEA, 2023.

Beyond recycling, second-life applications for batteries provide an additional pathway to reduce primary demand. Electric vehicle batteries typically retain up to 80% of their capacity after their first use and can be repurposed for stationary energy storage. Pilot projects—such as those by Nissan and BMW—demonstrate the potential for battery reuse to extend material lifetimes and reduce overall resource demand (IEA, 2023, 184).

Beyond end-of-life products, secondary supply can also be derived from mine tailings and industrial by-products. Emerging approaches such as re-mining and phytomining demonstrate the potential to recover valuable materials from existing waste streams, improving resource efficiency while reducing environmental impacts (Crebo-Rediker & Khan, 2026; Holley et al., 2025). Lithium has been derived from oil and gas wastewater, and several closed-loop rare-earth magnet recycling and manufacturing ecosystems have emerged within established companies and start-ups, also by recovering e-waste (Crebo-Rediker and Khan, 2026). In the U.S., recovering even 1% of by-products from existing domestic metal mining operations would substantially reduce reliance on imports (Holley et al., 2025). Given the scale of mining activity in Southeast Asia, these pathways could represent an important, but largely untapped, supplementary source of supply (Bilek, 2023).

Despite these developments, Southeast Asia remains significantly behind in both recycling capacity and policy integration. The region generates large and growing volumes of electronic waste—over 3.5 million tons in 2019—yet recycling rates remain low, estimated at around 11.7%, compared to over 40% in Europe (Bilek, 2023). While there are emerging initiatives, such as battery recycling investments in Singapore and Indonesia, these remain fragmented and small-scale relative to the pace of mineral demand growth.

4.2 MATERIAL EFFICIENCY, TECHNOLOGICAL SUBSTITUTION, AND DEMAND REDUCTION

In addition to recycling, improvements in material efficiency and product design offer important opportunities to reduce overall demand for critical minerals. Advances in manufacturing processes, product design, and technology optimization can significantly reduce the quantity of minerals required per unit of output. These efficiency gains can play a substantial role in moderating future mineral demand, particularly when combined with circular economy strategies (Hund et al., 2020).

The environmental footprint of mineral production also varies significantly across extraction and processing pathways. For example, producing battery-grade nickel from laterite ores is considerably more energy-intensive than production from sulfide deposits, while synthetic graphite anodes are associated with higher emissions than natural graphite alternatives. Despite these differences, lower-emission production pathways are not consistently prioritized in investment or sourcing decisions (IEA, 2021). While some battery manufacturers have begun tracking supply chain emissions and favoring lower-impact materials, this practice is not yet widespread (ibid.). An example in this context is the concept of a “battery passport” by the Global Battery Alliance, similar to that developed in 2017 by the European Union (European Commission, n.d.), to identify and track batteries throughout their lifecycle that could also help harmonize regulations on international shipments for recycling (GBA, 2021).

Technological innovation offers further opportunities to reduce dependence on specific minerals through substitution. This is particularly evident in battery technologies. Lithium iron phosphate (LFP) batteries eliminate the need for cobalt and significantly reduce reliance on nickel (IEA, 2021), while sodium-ion batteries have experienced rapid development in recent years in China, and all-solid-state batteries (ASSBs) could further transform material demand, particularly in stationary storage and lower-performance mobility segments (IEA, 2023). Although these technologies are not yet universal substitutes, they illustrate how innovation can reshape material demand over time.

Substitution is also relevant beyond batteries. In electric vehicle motors, for example, most current designs rely on permanent magnets containing rare earth elements such as neodymium, dysprosium, and terbium. However, alternative motor technologies. These include: (i) improving material efficiency in magnet production to reduce REE content while maintaining performance; (ii) reducing the quantity of permanent magnets required in motor design; and (iii) substituting permanent-magnet motors with REE-free alternatives such as induction or switched reluctance motors (IEA, 2021) or leapfrogged innovations such as the iron nitride permanent magnets (Crebo-Rediker and Khan, 2026).

More fundamentally, demand-side measures can also play an important role in reducing mineral dependence. The scale of critical mineral demand is closely linked to the structure of energy and transport systems. Reducing reliance on private vehicle ownership, expanding public transportation, and promoting shared mobility can significantly decrease demand for battery materials such as lithium, nickel, and cobalt—particularly in rapidly urbanizing Southeast Asian cities (Hund et al., 2020; Walter et al., 2024).

Taken together, these pathways—recycling, material efficiency, technological substitution, and demand reduction—demonstrate that future mineral demand is not fixed. Instead, it can be shaped by policy choices, technological innovation, and system-level changes. However, as the following section shows, these approaches remain only partially integrated into policy frameworks across Southeast Asia.

POLICY GAPS AND OPPORTUNITIES

Across Southeast Asia, governments have developed increasingly detailed policies to support mining, mineral processing, and EV industrialization, but policies on recycling, e-waste, and circularity remain underdeveloped, fragmented, or poorly integrated into mineral strategies. Where circular economy frameworks exist, they are typically confined to environmental and waste management domains, with limited coordination with mineral, industrial, or trade policy. At the global level, e-waste growth is far outpacing recycling efforts (Baldé et al., 2024). [1] [DAT2] At the regional level, ASEAN generates significant e-waste, with Indonesia generating a staggering 1,900 billion kg as one of the highest in all of Asia, while Singapore and Brunei having the highest per-capita e-waste generation (20-25kg), followed by Malaysia and Thailand (15-20kg) (ibid.). Meanwhile, legislation on e-waste is often insufficient (Bilek, 2023), as is the lack of data, including on key e-waste-related issues such as hibernation.

Table 4: Recycling, E-waste, and Circular Economy advancements and key policy gaps

Country	Main Policies & Developments	Key Policy Gap
Malaysia	E-waste regulated under Environmental Quality (Scheduled Wastes) Regulations 2005; circular economy strategies (National Strategic Plan 2018–2030; Circular Economy Blueprint); voluntary certification for repairability; growing EV battery and recycling investment promotion	Policies focus on waste management and compliance, not strategic recovery of critical minerals; limited integration with mineral or industrial policy; informal sector and infrastructure gaps constrain recovery
Singapore	Resource Sustainability Act establishes EPR system for e-waste; strong national collection system; battery recycling investments (e.g., TES facility); high collection volumes achieved	Strong governance model, but not linked to critical minerals strategy; focus is on urban waste efficiency rather than supply-chain security
Indonesia	Strong EV and mineral industrial policy (Presidential Regulation 55/2019); hazardous waste regulation (GR 101/2014); Circular Economy Roadmap (2025–2045) includes electronics; early-stage e-waste system	Major policy imbalance: strong upstream (nickel–EV), weak downstream recovery; no comprehensive e-waste law; no EPR; limited recycling infrastructure
Philippines	General waste framework (RA 9003); DENR DAO 2013-22 on WEEE; Revised National Solid Waste Management Strategy (2021); EV policy (EVIDA) includes disposal provisions	No dedicated e-waste or mineral recovery policy; recycling framed as waste management; weak infrastructure and enforcement; limited integration with EV/mineral strategy
Vietnam	Law on Environmental Protection (2020) introduces EPR; Decree 31/2020 regulates EEE imports; circular economy framing emerging; mineral law emphasizes resource efficiency	Stronger conceptual integration of circularity, but weak implementation; recycling not yet linked to critical minerals or EV supply chains
Thailand	Hazardous Substance Act (1992); National E-waste Plan (2018) and Strategic Plan (2022–2026); draft WEEE and DIWMA (EPR-based); strong EV and battery innovation (	No enforceable e-waste law; fragmented governance; heavy reliance on informal sector; innovation not integrated into circular policy frameworks

MALAYSIA

Malaysia's policy framework combines established regulatory controls, emerging circular economy initiatives, and growing industrial promotion of recycling. E-waste is regulated under the Environmental Quality (Scheduled Wastes) Regulations 2005, which classify electronic waste—including batteries—as hazardous materials requiring controlled handling and disposal (Government of Malaysia, 2005; Baldé et al., 2024). Enforcement is supported through inspections, licensing requirements, and penalties for non-compliance.

In parallel, Malaysia has introduced broader circular economy policies, including the National Strategic Plan for Solid Waste Management (2018–2030) and the Circular Economy Blueprint for Solid Waste (KPKT, 2025). These frameworks promote resource efficiency, recycling, and the development of e-waste collection and recovery systems, including Extended Producer Responsibility (EPR) elements (Baldé et al., 2024). However, these initiatives remain primarily framed within waste management policy, rather than as part of a strategic approach to critical mineral recovery.

At the same time, Malaysia is actively positioning itself as a regional hub for investment in EV battery and e-waste recycling, with government agencies highlighting its potential for industrial upgrading and technological development (MIDA, 2024).

This expansion has been accompanied by persistent challenges, including illegal e-waste imports and environmentally risky processing practices, prompting enforcement actions such as recent import restrictions (Interpol, 2020; Symons, 2026). Structural constraints, including the continued role of informal recycling and limited collection and processing infrastructure, further restrict material recovery (Faradillah et al., 2026). Emerging developments in material substitution, such as the deployment of sodium-ion batteries, indicate early efforts to reduce dependence on critical minerals. However, these remain nascent and only weakly integrated into broader policy frameworks (Wong, 2025).

SINGAPORE

Singapore represents the most developed case of e-waste governance in Southeast Asia. The Resource Sustainability Act establishes an Extended Producer Responsibility (EPR) system for e-waste, placing responsibility for collection and treatment on producers (NEA, n.d.). A well-developed national collection system and targeted investments in recycling infrastructure support these policies.

Singapore's broader waste strategy explicitly identifies e-waste as a priority stream within a circular economy approach. The government has also promoted investments in battery recycling, including facilities designed to recover materials for reuse in new batteries (EDB Singapore, 2020).

By 2025, more than 34,000 tonnes of e-waste had been collected and recycled under the national system (Puthucheary, 2025).

Despite these achievements, the policy framework remains primarily oriented toward waste governance and urban resource efficiency. It is not explicitly integrated into a broader critical minerals' strategy, and the focus remains on managing waste streams rather than developing secondary supply as part of mineral security.

INDONESIA

Indonesia illustrates a pronounced policy imbalance. The country has developed one of the most comprehensive mineral and EV industrial strategies in the region, centered on nickel extraction, refining, and battery manufacturing. Presidential Regulation 55/2019 created the core framework for battery-electric vehicle development and, as later ASEAN analysis notes, requires battery waste to be handled through recycling and/or waste management (Bilek, 2023). However, policies addressing recycling and secondary supply remain comparatively underdeveloped.

E-waste is regulated under the Hazardous and Toxic Waste Management Regulation (Government Regulation No. 101/2014), which primarily focuses on safe handling, transport, and disposal rather than on material recovery (FAO, 2014). Circular economy initiatives, including the National Circular Economy Roadmap (2025–2045), - identify electronics and e-waste as a priority sector and emphasize resource efficiency and recycling, but remain only loosely connected to mineral and EV industrial strategies (BAPPENAS, 2024; ITU, 2023).

In practice, Indonesia does not yet have a comprehensive standalone e-waste law, and Extended Producer Responsibility (EPR) has not been fully implemented (ITU, 2023). Formal recycling capacity remains limited, and a significant share of e-waste is processed informally or disposed of in landfills, creating environmental and health risks (SUPRA, 2024). The National Action Plan on E-waste Management (2020–2025) aims to address these challenges through improved regulation, infrastructure development, and public awareness (ITU, 2023), but implementation remains ongoing. As a result, Indonesia's strong upstream and industrial strategy is not matched by equivalent development in downstream recovery systems.

PHILIPPINES

The Philippines presents a similar, though less developed, case. The government has introduced policies to support EV adoption, particularly through the Electric Vehicle Industry Development Act (EVIDA), which includes provisions on the proper disposal, reuse, and recycling of EV components such as batteries (Philippine Senate, 2022). However, circular economy and e-waste policies remain fragmented and largely embedded within broader waste management frameworks.

The Ecological Solid Waste Management Act (Republic Act No. 9003) provides the core regulatory framework, promoting waste segregation and environmentally sound disposal (Government of the Philippines, 2000). Additional guidance is provided by DENR Administrative Order No. 2013-22 on the management of waste electrical and electronic equipment (WEEE) and the Revised National Solid Waste Management Strategy (2021) (DENR, 2013; National Solid Waste Management Commission, 2021). While these policies support improved handling of e-waste, they are not designed to facilitate systematic material recovery or integration into mineral supply chains.

Implementation challenges remain significant. Limited access to formal collection and recycling infrastructure, particularly outside major urban centers, contributes to widespread informal processing and improper disposal. As a result, e-waste management remains focused on waste handling rather than resource recovery, and its integration into mineral and industrial strategy remains limited.

In terms of technological development, material substitution efforts are emerging but remain limited. For example, domestic initiatives are exploring sodium-ion battery technologies as alternatives to conventional lead-acid batteries, offering longer life cycles and reduced dependence on critical minerals such as lithium (Eva, 2025). However, innovation in battery technologies remains nascent and concentrated primarily on sodium-ion and lithium-ion systems, with limited broader diversification

VIETNAM

Vietnam represents a transitional case in which policy frameworks increasingly incorporate circular economy principles, but implementation remains uneven. The Law on Environmental Protection (2020) introduces Extended Producer Responsibility (EPR), establishing obligations for the collection and recycling of several product categories, including electrical and electronic equipment (Government of Vietnam, 2020; VMRF, 2023). This policy provides one of the more comprehensive legal bases for circularity in the region.

In parallel, reforms to mineral governance, including the Law on Geology and Minerals, emphasize resource efficiency, environmental protection, and the adoption of circular economy models in mineral extraction and processing (Rajah & Tann, 2025). Additional policy instruments, such as the National Action Plan on e-waste management (2020–2025), aim to strengthen collection systems and promote reduce–reuse–recycle (3R) principles (Baldé et al., 2024).

However, implementation challenges persist. E-waste management systems remain underdeveloped, with limited collection capacity, weak enforcement, and continued mixing of e-waste with general waste streams. While private-sector initiatives are emerging, they remain fragmented and limited in scale. As a result, circularity is increasingly present at the policy level but not yet fully operationalized in practice.

THAILAND

Thailand has made significant efforts to develop a circular-economy approach to e-waste, but its policy framework remains fragmented and incomplete. E-waste is primarily governed under broader legislation, including the Hazardous Substance Act B.E. 2535 (1992), which regulates hazardous materials but is not specifically designed for e-waste recovery or circular material flows.

Thailand is one of the largest e-waste generators in Southeast Asia, producing approximately 753,000 tons (753 million kg) of e-waste in 2022 (ITU, 2024). The government has introduced the National E-waste Management Plan (2018) and the Strategic Plan on Integrated E-waste Management (2022–2026), which promote improved collection, recycling, and public awareness. Draft legislation based on Extended Producer Responsibility (EPR), including a proposed WEEE Act and Industrial Waste Management Act (DIWMA), remains under development (Baker McKenzie, 2025).

In practice, e-waste management relies heavily on the informal sector, which plays a central role in collection and recycling but often operates under unsafe conditions and with low recovery efficiency. Material flow studies indicate that a large share of e-waste is processed manually, with only partial recovery of valuable materials due to hibernation. At the same time, non-recoverable components are disposed of through landfilling or incineration (Baldé et al., 2024). Thailand is also affected by illegal transboundary e-waste flows, which further strain regulatory systems.

At the same time, Thailand has demonstrated relatively strong capabilities in technological innovation, including developments in sodium-ion batteries, alternative materials, and recycling technologies (NXPO, 2024; Reccessary, 2024). However, these advances remain only partially integrated into national circular economy and recycling policy frameworks.

Taken together, these cases reveal a clear structural imbalance across Southeast Asia. Governments have made substantial progress in developing policies to support extraction, processing, and industrialization, but have been far less active in building systems for material recovery and secondary supply. In effect, circular economy measures remain institutionally separated from the core economic strategies that drive mineral development, limiting their impact on long-term supply security. By contrast, mining, refining, and EV industrialization are embedded within broader economic, industrial, and trade strategies. This creates a disconnect: the same governments seeking to secure mineral inputs for future industries are not yet systematically investing in recovering those materials at the end-of-life stage. As a result, alternative pathways—recycling, reuse, material substitution, and innovation—remain peripheral rather than central to critical mineral policy. Addressing this imbalance will be essential to improving resource efficiency, reducing environmental impacts, and strengthening long-term supply security in the region.

Policy Recommendations

1. INTEGRATE CIRCULAR ECONOMY INTO MINERAL AND INDUSTRIAL STRATEGIES

Governments should embed circular economy objectives directly into critical minerals and industrial policy frameworks, rather than treating them as environmental add-ons. This includes incorporating material recovery targets, developing recycling capacity, and integrating secondary supply into national mineral strategies and EV roadmaps. Ministries responsible for industry, energy, and trade should coordinate with environmental agencies to ensure that circularity becomes a core pillar of supply security rather than a parallel policy track.

2. DEVELOP DEDICATED AND ENFORCEABLE E-WASTE AND BATTERY RECYCLING MECHANISMS

Countries without comprehensive frameworks—particularly Indonesia, Thailand, and the Philippines—should prioritize adopting dedicated e-waste legislation with enforceable provisions. This should include Extended Producer Responsibility (EPR) systems with mandatory collection and recycling targets, clear rules for EV battery end-of-life management, and certification and monitoring systems for recyclers. Moving from voluntary or fragmented systems to enforceable frameworks is essential to shift recycling from a waste-management issue to a strategic component of mineral supply chains.

3. INVEST IN FORMAL RECYCLING AND MATERIAL RECOVERY INFRASTRUCTURE

Public investment, blended finance, and targeted incentives should be used to scale formal collection, sorting, and recycling systems. Priority areas include national collection systems for e-waste and EV batteries, advanced recycling facilities (to focus on direct recycling technologies), and integration of informal sector actors into formal systems through training and certification. Without sufficient infrastructure, a large share of e-waste will continue to be processed informally or lost to landfills, limiting material recovery and increasing environmental risks.

4. SUPPORT INNOVATION, MATERIAL SUBSTITUTION, AND CLEANER PRODUCTION PATHWAYS

Governments should expand support for research, development, and deployment of technologies that reduce dependence on critical minerals. This includes:

- Battery innovation (e.g., sodium-ion, solid-state technologies)
- Material efficiency improvements in manufacturing
- Substitution technologies (e.g., REE-free motors, alternative chemistries)
- Cleaner processing pathways with lower emissions

These efforts should be linked to industrial policy through incentives, pilot projects, and partnerships with private firms and research institutions, enabling countries to move into higher-value and less resource-intensive segments of the value chain.

Policy Recommendations

5. STRENGTHEN GOVERNANCE, ENFORCEMENT, AND DATA SYSTEMS

Effective regulation requires stronger enforcement capacity and better data. Governments should improve monitoring and traceability of e-waste and secondary materials, strengthen enforcement against illegal e-waste imports and informal processing, develop national data systems on e-waste flows, recycling rates, and material recovery. Improved governance is essential to reduce environmental and health risks while increasing the efficiency and credibility of recycling systems.

6. STRENGTHEN REGIONAL AND INTERNATIONAL COOPERATION AND PARTNERSHIPS FOR CIRCULAR SUPPLY CHAINS

Regional and international cooperation will be critical to overcoming structural constraints and accelerating the transition toward circular, low-carbon mineral supply chains in Southeast Asia. At the regional level, ASEAN can play a stronger coordinating role by harmonizing e-waste regulations and extended producer responsibility (EPR) standards, facilitating cross-border recycling markets and investment, and developing shared data frameworks and best-practice guidelines. Such coordination would help address scale limitations within individual countries and enable more efficient, integrated recycling ecosystems across the region.

At the same time, governments should leverage international partnerships not only to secure access to raw materials, but to support technological leapfrogging and innovation. Through strategic economic diplomacy, countries can attract investment, technology transfer, and joint ventures in recycling, material innovation, and next-generation battery technologies. This includes negotiating agreements that embed local capability-building and co-development of technologies, while prioritizing partnerships in recycling, recovery, and advanced materials.

By aligning regional cooperation with forward-looking international partnerships, Southeast Asian countries can position themselves as hubs for circular and low-carbon supply chains. This dual approach would enable movement into higher-value segments of the supply chain, reduce long-term dependence on primary extraction, and strengthen strategic and economic resilience.

Conclusion

Southeast Asia has emerged as a central player in global critical mineral supply chains, with governments actively promoting mining, processing, and EV industrialization. However, current strategies remain heavily supply-driven, with comparatively limited attention to recycling, material substitution, and demand reduction. While several countries have introduced circular economy initiatives and e-waste policies, these are typically fragmented and weakly integrated into mineral strategies. As a result, opportunities to recover valuable materials, reduce environmental impacts, and enhance long-term supply security remain underdeveloped. A more balanced approach is needed. Critical minerals are essential for the energy transition, but strategies that rely primarily on expanding extraction risk reproducing the environmental and social costs historically associated with resource booms. Integrating recycling, innovation, and circular economy principles into mineral policy will be essential to ensure that Southeast Asia's role in the energy transition is not only economically competitive but also environmentally sustainable and strategically resilient.

Appendix

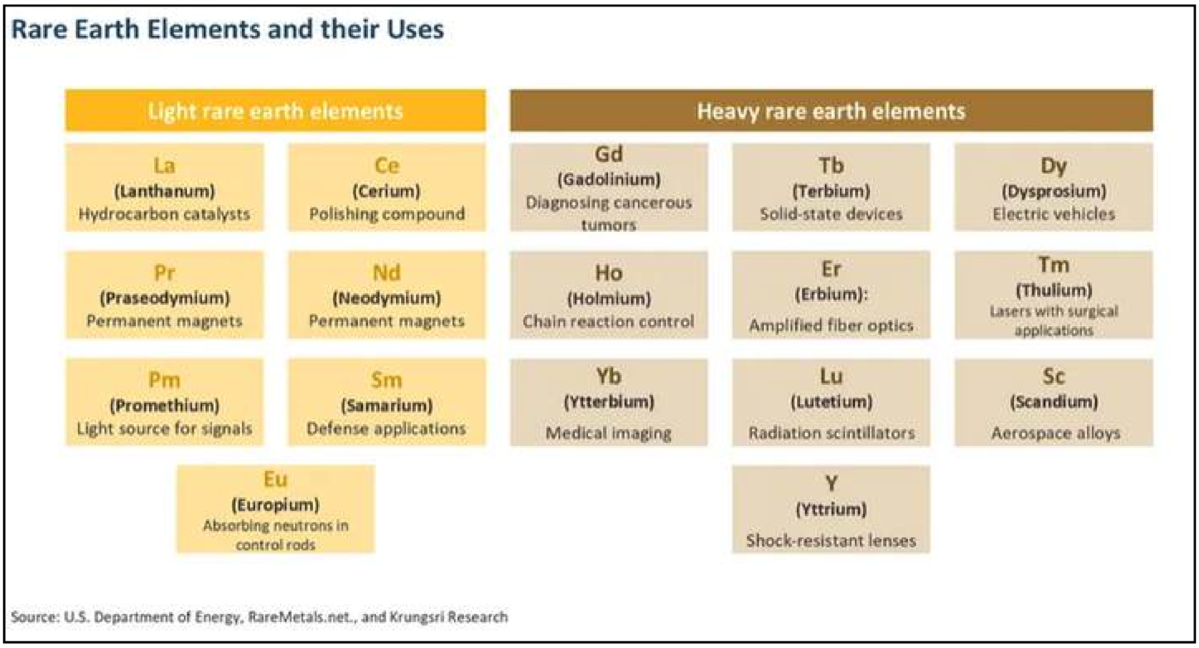

Figure A1. Rare Earth Elements and their Uses. Source: Leenoi, 2025.

Summary of motor types

	Mineral use	Current status and examples
Permanent-magnet synchronous	Neodymium, dysprosium, dysprosium, terbium	Used in all HEV and most PHEV and BEV
Induction	No rare earths; but significant copper or aluminium use	Some BEVs (e.g. Tesla S, Mercedes B)
Permanent-magnet without REE	No rare earths; potentially some nickel and cobalt use	Prototypes using ferrite or AlNiCo magnets
Switched reluctance	No rare earths or copper	First prototypes

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