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ACOPS

ABOUT NICKEL & OUR APPETITE FOR IT

Where is it found, on land and at sea? In what ecosystems?
Who extracts it, where, how and what for?

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There is a fierce and ongoing debate about the acceptability of seabed mineral mining that includes whether its environmental impact would exceed that of terrestrial mining. However, most reports embrace either a pro-environment or pro-industry perspective, relying on different data sources, methodologies, and numbers. They also examine little the impacts of land mining, the implications of using different technologies or approaches in different areas, or the broader forces shaping these activities.

This factsheet presents our own investigation of the peer-reviewed literature (where available), starting with nickel, a mineral found both on land and on the seabed. We attempt to form an independent view on the drivers of exploitation and environmental impacts from land mining compared with seabed mining and the scientific uncertainty attached. Four key takeaway points are that

(1) The high environmental standards (legitimately) being developed in the seabed mining exploitation code are not applied on land;

(2) There is not enough data for a comparison of nickel mining on land and at sea to be possible without undertaking a research project on the topic. One recent publication even suggests that such comparison would involve, if not equate more to, a policy assessment than a scientific comparative assessment - yet there appears to be little appetite to explore it.

(3) Political (including geopolitical) factors, rather than scientific data (especially environmental) or international law, appear to be main drivers of decision-making; and,

(4) The complexity of the forces at play makes it difficult to reliably anticipate developments in this policy debate.

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What and where?

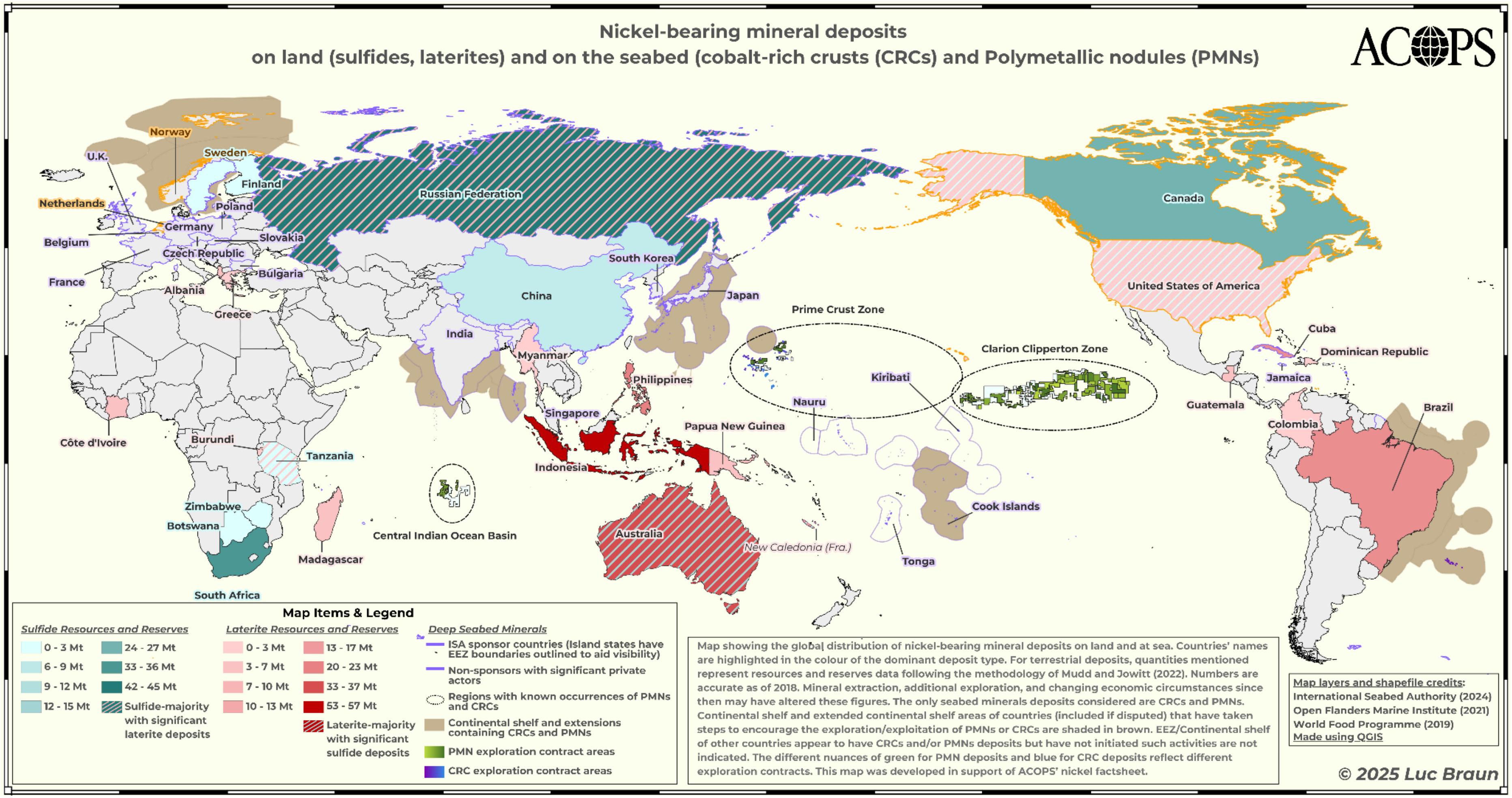
nickel (Ni) is a chemical element and categorised as a metal in the periodic table. While it is one of the most abundant elements on Earth, it is more heavily concentrated in the Earth's core and mantle than the minable crust (Haynes et al. 2016). Economic deposit formation is contingent on geophysical processes, four of which give rise to the main deposits being considered on land and the ocean floor: magmatic sulphides and laterites on land, and nodules, crusts and sulfides at the seafloor (Mudd and Jowitt 2022; Kuhn and Rühlemann, 2021; the Geological Survey, nd; Wang et al., 2009).

On land - sulphides and laterites

Magmatic sulphide deposits are volcanic in origin. They occur relatively deep in the subsoil, and are mined in underground mines (Mudd and Jowitt 2022). The majority of nickel-bearing magmatic sulphide deposits are found in Canada, Russia, Australia and South Africa (figure 1). They accounted for the majority of global nickel production from the early 1900s up until the early 21st century (Mudd and Jowitt 2022).

The other main deposit type, the laterite, is formed under tropical conditions from the weathering of ultramafic rocks, rocks low in silicon, and high in magnesium, iron, and other metals. Laterite deposits are shallow, and cover larger areas compared to sulphide bodies, resulting in their exploitation through open-pit mines often located in rainforests. There are three types of nickel-bearing minerals in a laterite profile - each type is associated with a particular layer of the laterite profile (Mudd and Jowitt 2022) (see figure 2). Different processing methods are required to extract the nickel metal from the different layers, due to their different composition in different minerals (Crundwell et al. 2011).

By 2018, nickel laterites, driven by the exploitation of saprolitic ore in Indonesia and the Philippines, surged to beyond 60% of global nickel production (Mudd and Jowitt 2022). In 2022, Indonesia alone was responsible for 48.5% of global nickel production -the Philippines' share stood at 10% (US. Geological Survey 2023). With mining continuing to expand in these countries, this trend is expected to accelerate in the future as known resources of nickel in these countries are found in laterites (Mudd and Jowitt 2022).



Map showing the global distribution of nickel-bearing mineral deposits on land and at sea. Countries' names are highlighted in the colour of the dominant deposit type. For terrestrial deposits, quantities mentioned represent resources and reserves data following the methodology of Mudd and Jowitt (2022). Numbers are accurate as of 2018. Mineral extraction, additional exploration, and changing economic circumstances since then may have altered these figures. The only seabed minerals deposits considered are CRCs and PMNs. Continental shelf and extended continental shelf areas of countries (included if disputed) that have taken steps to encourage the exploration/exploitation of PMNs or CRCs are shaded in brown. EEZ/Continental shelf of other countries appear to have CRCs and/or PMNs deposits but have not initiated such activities are not indicated. The different nuances of green for PMN deposits and blue for CRC deposits reflect different exploration contracts. This map was developed in support of ACOPS' nickel factsheet.

Figure 1- Global distribution of nickel-bearing mineral deposits on land and on the seabed

Research contribution from ACOPS, a non-campaigning knowledge NGO whose mission is the protection of the marine environment through the rule of law and sound science. Accordingly we do not take a view on the merits or otherwise of activities in the Area, including seabed mining. However we consider that the precautionary approach is applicable to all decisions by the ISA. However we consider that the precautionary approach is applicable to all decisions by the ISA.

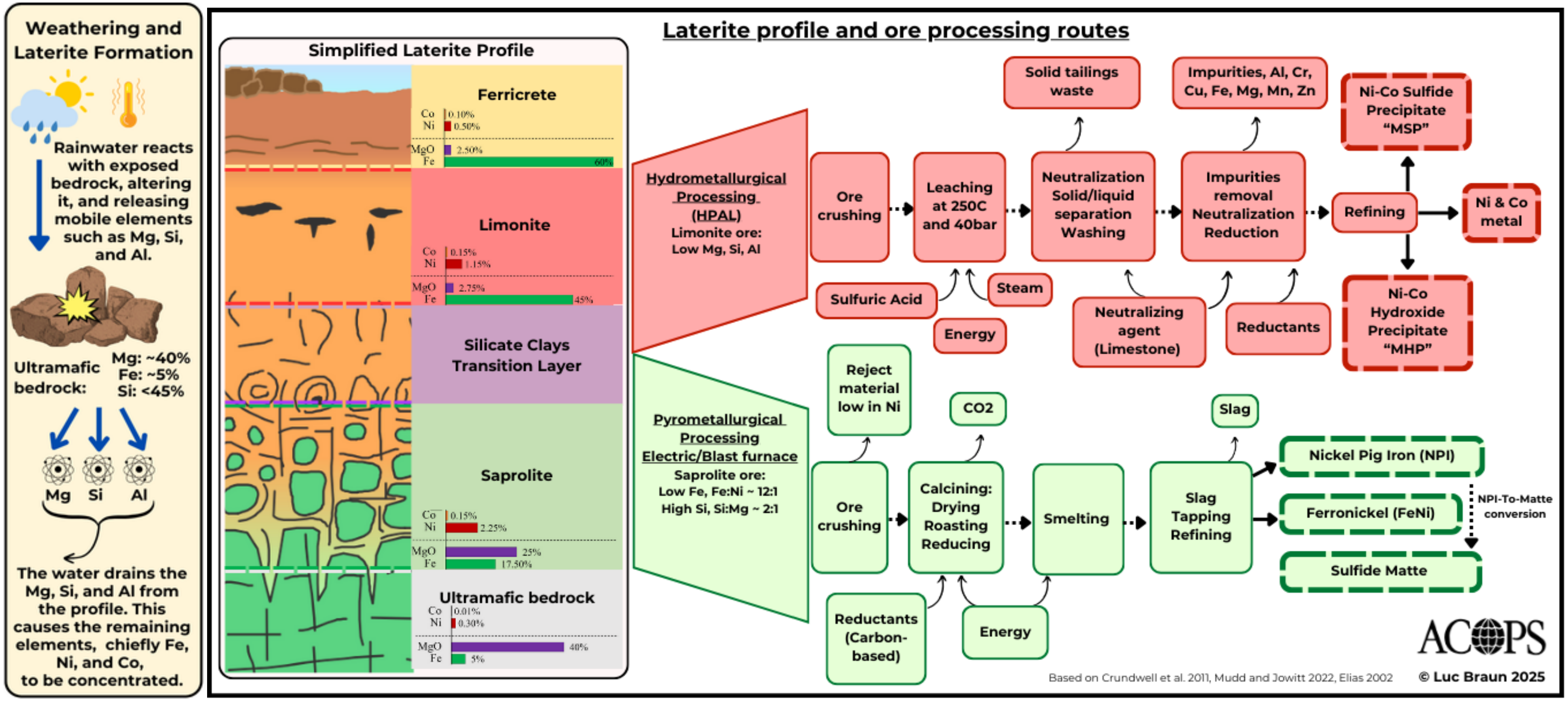


Figure 2 - Laterite profile and associated processing for nickel extraction

At Sea

At sea, nickel occurs in different deposit forms: nodules, and crusts (Kuhn and Rühlemann 2021; McKelvey et al. 1983, Wang et al. 2009). Of those two deposit types, nodules are currently estimated to contain the highest amount of nickel. Nodules also include other metals alongside nickel, such as manganese, cobalt, copper and titanium (hence their commonly used name of 'polymetallic' nodule) (Hein et al. 2020). These resources are located both within national jurisdiction (e.g Norway, Cook Island, Tonga) and beyond national jurisdiction where exploration and exploitation can only occur with the authorisation of the International Seabed Authority (ISA) - a regulating entity also charged with the protection of the marine environment against these activities. A third deep seabed mineral deposit type, seafloor massive sulfides[1], typically associated with hydrothermal vents, is not included in this discussion for its negligible nickel content (Peterson et al. 2016, Hannington et al. 2005).

Nodules form on the seafloor through the precipitation of dissolved metals onto a bio-seed; the minerals bind to the film of microorganisms and create micro-nodules (Verlaan and Cronan 2022). Their slow growth process is estimated to take 1 to 2 million years (Petersen et al. 2016, Wang and Müller 2009, Hein et al. 2020). Nodules occur both beyond and within countries' national jurisdiction. They occur in abyssal plains of the Eastern and North-Eastern Pacific, and in the Atlantic, and Indian Oceans (Peterson et al. 2016; see figure 1 above). Their nickel content, chemical composition, and specific type vary depending on their specific location. Nodules from the Pacific are estimated to contain higher amounts of nickel than nodules from the Atlantic and Indian oceans by about a factor of 1.2 times for combined nickel and copper content (Hein et al. 2020, McKelvey et al. 1983). However, some authors highlight that nodule abundance and their mineral composition are less well known outside the Clarion Clipperton Zone (in the Northeast Pacific Ocean) meaning that their occurrence in other seabed areas may be underestimated (Peterson et al. 2016).

Crusts form on hard volcanic rock in areas where no sediment deposition takes place, around a specific bio-seed: marine calcareous micro algae; calcium from the algae bind with manganese oxide and accumulate on the volcanic rock. They slowly grow over 1 to 6 million years, accumulating minerals such as nickel and cobalt (Wang and Müller 2009). They can be found on seamounts and ocean plateaus at depths between 400 and 5000 metres (Peterson et al. 2016). Although they are most abundant in the Pacific Ocean, they also occur in the Atlantic and Indian oceans. About 44% of crusts considered to be valuable for commercial exploitation occur under the exclusive jurisdiction of coastal countries (Petersen et al. 2016; Wang and Müller, 2009). Assumptions made to calculate the amount of minerals in crusts vary. A recent estimate finds that the South Pacific holds the highest amount of nickel (4643 t.), closely followed by the Pacific Prime Crust Zone (4209 t.) (Mizell et al. 2022).

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[1] As seawater comes into contact with the magma below, it is heated up and pushed back upwards as a hot, mineral-enriched hydrothermal fluid, mixes with the surrounding cold seawater, solidifies and form chimney-like structures (Hannington et al. 2005, Hannington et al. 2010)

What for? What are the projected needs?

Nickel today is used primarily for the production of some types of stainless steel (65%), batteries (15%), alloys and superalloys (8%), special steels (5%) and for electroplating (6%) (Nornickel 2024); figure 3(A). Different end-uses require different nickel products (e.g. nickel pig-iron (NPI), nickel metal; figure 3(B). These products were historically split into high and low grades, according to their suitability for different end-uses, although not all nickel products fall neatly within these two categories. In particular, stainless steel producers favour low-grade nickel products (e.g. NPI, FerroNickel). Specialised alloys and steels, used for the manufacturing of aerospace and medical manufacturers, on the other hand require high-purity nickel metal as an input. Battery production historically preferred high-purity nickel metal. Recent trends, however, have instead seen manufacturers source lower-purity nickel compounds as a more cost-effective precursor material. Globally, around a fourth of primary nickel production is in traditional high-grade products, around 60% is "low-grade".

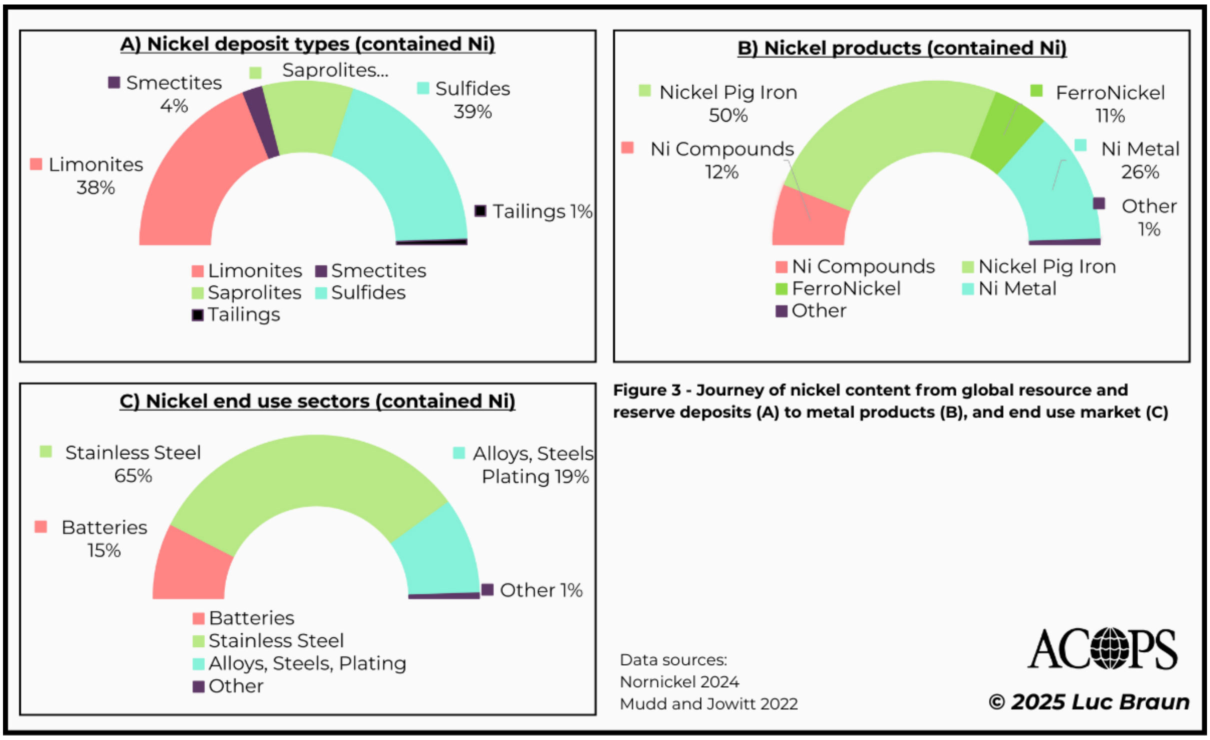

Figure 3 - Journey of nickel content from deposit (A) to metal products (B) to end use market (C)

It is generally accepted, that nickel will become a metal of central importance for the renewable energy transition as a key ingredient in Nickel-Manganese-Cobalt (NMC) Lithium Ion batteries, as well as due to ancillary roles in geothermal and offshore wind electricity generation (Salgado et al. 2021, IEA 2021, Simas et al. 2022, World Bank 2020). Nickel has been identified as a critical raw material by the US, and as a strategic raw material by the EU. These statuses are conferred based on its future importance as an ingredient in renewable energy technologies, projected demand, and the current concentration and ownership structures of its production and processing capacities (European Commission 2023, DoE 2023 Critical Minerals Assessment).

There is, however, an on-going debate on the extent of this 'need' for nickel in the future, with arguments centred around new technologies and revised societal needs or standards (Simas et al. 2022). Battery chemistry developments, especially the role of Ni- and Co-poor LFP batteries, popular with Chinese automakers, could impact the demand for nickel in the long term (IEA 2024). Current thinking, as revealed in reports from the International Energy Agency (IEA) and the World Bank, as well as other industry players (e.g. Benchmark) and Environmental Non-Governmental Organisations (ENGOs; in particular WWF), foresee the need to increase nickel production over 2020s and 2030s to meet demand, at least from early-generation electric vehicle batteries. By contrast, demand from other end uses will only grow modestly in the same time frame (IEA Mineral Demand Tool).

Some time before 2050, primary production of nickel is predicted to peak as secondary production from the recycling of built-up nickel stock becomes significant (Simas et al. 2022, IEA 2021, World Bank 2020).

Differences in analyses of production needs reflect varying approaches to societal needs and duties, technology development, political feasibility and the market readiness. For example, the IEA and WWF produce diverging estimates (IEA 2021, Simas et al. 2022). The IEA calculated that total nickel mining would more than double by 2040 compared to 2022 levels in a scenario where humanity limits global warming to well below the 2°C global average, the current goal of the Paris Agreement (IEA 2021, IEA 2024). WWF on the other hand, using similar assumptions about future energy market parameters such as electrification, energy generation, and shares of renewable technologies, initially projects far higher nickel demand. The introduction of circular economy measures, however, could cut this demand by 40-50% (Simas et al. 2022), although this assessment is global, assuming frictionless technology diffusion and accessibility.

The IEA scenario places an upper bound on the cumulative nickel demand of around 190 Mt by the middle of the century, with half of this, 95 Mt, devoted to energy transition technologies (IEA Mineral Demand Tool). For reference, WWF forecasts cumulative nickel demand figures ranging from 173 Mt in the most nickel-intensive scenario to 84 Mt in the least nickel-intensive scenario (Simas et al. 2022).

Land-based resources and reserves today are estimated to contain some 350 Mt of nickel - at most 240 Mt of this contained in limonitic laterite and sulphide ores suitable for energy transition technologies (Mudd and Jowitt 2022). With some 10% needed for special steels and alloys, 216mt remain available for battery-grade nickel, more than the projected demand of 95Mt, 173Mt, and 84 Mt (Nornickel 2022, IEA Mineral Demand Tool, Mudd and Jowitt 2022, Simas et al. 2022). However, these figures are highly sensitive to a number of factors such as variations in the price of nickel. For example, downward pressure on nickel product prices as a result of market surpluses from Indonesian nickel expansion can make the extraction of new deposits around the world less commercially viable. Many producers, primarily outside of Indonesia, today face considerable challenges in this market environment (Hunt et al. 2024, Fildes 2024).

As a result, the current demand projections do not exceed total nickel resources on land, with the caveat that this assessment includes all resources, a significant share of which may never see conversion into confirmed 'reserves'.

The focus on the seafloor may therefore be driven by other dynamics, including perhaps alleged environmental trade-offs, geopolitics, and supply chain diversification. By comparison, nickel in polymetallic nodules in the Clarion Clipperton Zone, alone, has been estimated by the ISA at between 270 and 393 Mt (ISA 2010).

Environmental impact from terrestrial mining

Unlike seabed mining, environmental impacts from land mining appear to benefit from tacit social acceptance globally until major environmental disasters have direct adverse effects on populations. Environmental impacts from terrestrial mining, including processing, are broadly summarised below.

Land transformations, pollution and adverse effects including habitat and biodiversity loss

Land use is defined as the surface area of land altered by mining activities (Iwatsuki et al. 2018). The Nickel Institute, an industry association, reports a land use intensity of 0.76m^2 /t(Ni) for underground mines (sulphides), and 1.8m^2/ t(Ni) for open-pit mines (laterites). These values are industry-wide averages – numbers for specific sites can vary significantly (Iwatsuki et al. 2018), though the trend of twice as high land use for open-pit mines compared to underground mines generally holds (Nakajima et al. 2017, Mudd and Jowitt 2022, Mervine et al. 2025, Tang et al. 2015). With nickel demand growing globally, and laterite mining set to dominate this increase, land use will drastically increase in the coming years.

Concerns from higher land use resulting from the shift from magmatic to lateritic nickel are especially tied to the concentration of these deposits in the global tropics (Mudd and Jowitt 2022, Mervine et al. 2025). The ultramafic rainforests cleared for mining activities store carbon which, if released, add to greenhouse gas emissions (Mervine et al. 2025, Coracero and Malabrigo 2020, Mudd and Jowitt 2022, Galey et al. 2017, Echevarria 2018). Emissions from the release of sequestered carbon are lower for non-tropical laterite deposits, for example in Australia (Mervine et al. 2025), though it is the tropical deposits of Southeast Asia on which the laterite boom is primarily founded (Mudd and Jowitt 2022). While processing and mining phases dominate contributions to CO2 emissions, the release of sequestered carbon is nonetheless generally not included in such studies. Finally, high levels of endemism caused by naturally elevated metal soil concentrations near laterite deposits also raises serious concerns around habitat removal and biodiversity loss, especially in the tropics (Anacker 2014, Galey et al. 2017).

Nickel mining activities have a number of impacts on local ecosystems and communities. Generally, open-pit laterite mines disturb their surroundings more profoundly than underground sulfide mines, though serious impacts remain for those too (Mudd and Jowitt 2022).

The world over, laterite mines on formerly vegetated land cause significant land degradation, as well as drive water- and airborne soil erosion (Voskoboynik and Farrugia 2022, Sellier et al. 2021, Prematuri et al. 2020, Taufik et al. 2022). Soil erosion also leads to increased sedimentation and heavy metals concentrations in rivers, estuaries, and coastal regions, as well as accumulation of these heavy metals in plant and animal species (Taufik 2023, Germande et al. 2022, Gonzalez and Ramírez 1995, Tabios 2015, Gunkel-Grillon et al. 2014). These impacts are of particular concern to communities reliant on healthy ecosystems for their drinking water, food supply, and economic livelihoods (Nasution et al. 2024, CRI 2024, Myllyvirta 2024). Fishing and agricultural communities in particular bear the brunt of these pressures (CRI 2024, Myllyvirta et al. 2024, Nasution et al. 2024, Kowasch 2017, Prematuri et al. 2020).

Ore processing represents another significant source of negative environmental impacts (CRI 2024, Nasution et al. 2024, Zhulidov et al. 2011, Crawford 1995, Pacheco et al. 1999, Winterhalder 1996). Following a series of escalating Indonesian ore export restrictions, firms rushed to erect smelters and acid leach plants in large-scale industrial parks across Sulawesi and Halmahera islands over the past two decades (Emont 2023, Emont 2024, Wood Mackenzie 2023). These parks are large sources of exhaust fumes and harmful airborne particles from metallurgical activities, captive coal power plants, and industrial and personal transportation equipment, with detrimental effects for workers and residents (Taufik 2023, Nasution et al. 2024, CRI 2024, Myllyvirta et al. 2024). Coal-fired thermal power plants, as well as metallurgical activities, further emit large amounts of greenhouse gases such as CO2 (Nasution et al. 2024, CRI 2024, Myllyvirta et al. 2024). Water discharge from coal power plants has also been reported to negatively impact coastal ecosystems (CRI 2024).

Tailings and mine waste rock storage facilities also pose a risk to local ecosystems (Nasution et al. 2024, Bartzas et al. 2021, Balbin et al. 2023). Hydrometallurgical tailings are highly toxic, and climatic and tectonic conditions in many of the countries where these processing projects are located make containing them safely a major concern (Stankovic 2020, Bartzas et al. 2021, Fisher and Grossl 2023, Balbin et al. 2023). Two fatal tailings dam failures in Morowali, Indonesia, in March 2025, as well as a landslide associated with an ore stockpile highlight the risk to human life, health, and local ecosystems from such activities (Earthworks 2025). On the other hand, acid mine run-off from waste rock, which is a major concern for mines targeting sulfide-hosted metals around the world, is generally not a concern in laterite mining, which targets oxide ores (Turingan et al. 2020, Balbin et al. 2023).

A long history of nickel production in places such as New Caledonia, Canada, Cuba, and Russia has resulted in a substantial experience of impacts on landscapes, ecosystems, and people (Zhulidov et al. 2011, Bird/UN 1984, Pacheco et al. 1999, Gonzalez and Ramirez 1995, Gonzales 1997, Filer 2017), despite the conduct of systematic and comprehensive analyses of impacts being generally lacking. Nevertheless, although case studies from these regions recognise challenges, they also conclude that pollution-limiting and land rehabilitation measures can be feasible and effective (Winterhalder 1996, Crawford 1995, Balbin et al. 2023, Varela et al. 2016, Carlom 2024).

Impacts from extraction and processing, including greenhouse gas emissions and energy costs
There are two broad types of nickel laterite ore processing routes that depend on the ore being mined. Pyrometallurgical processing is used for saprolite ores, hydrometallurgical processing is the preferred option for limonite ores (Crundwell et al. 2011) (figure 2).

Pyrometallurgical processing is the most common form of nickel laterite ore processing today. It is used nearly exclusively for saprolitic ores (Crundwell et al. 2011). The ore is ground, reduced, and then smelted, yielding a product rich in iron and nickel called ferronickel (FeNi) (Crundwell et al. 2011). Nickel Pig Iron (NPI, 5-20% Ni) is a novel, low-nickel FeNi popularised by Chinese companies over the past two decades as a low-cost alternative to traditional FeNi (20-40% Ni). Half of global nickel production is in NPI today, and all of it is produced from saprolite ores (figure 2).

Due to Ni and Fe's similar chemical properties, it is resource- and energy-intensive to further refine FeNi and NPI into higher-grade nickel products (Crundwell et al. 2011), making them the most carbon-, and energy-intensive nickel products on the market. This typically constrains them to low-grade applications such as stainless steel. A recent development, however, has seen producers convert NPI to the battery-grade precursor product nickel sulphide matte. NPI-to-matte conversion seriously weakens the environmental benefit of battery electric vehicles, and it is on the rise across the industry. For some specific values on energy and greenhouse gas production costs of common nickel products (Table 1).

There are several ***hydrometallurgical processing*** routes but High Pressure Acid Leaching (HPAL) is the dominant one.[2] It is a technically challenging process in which nickel and cobalt are leached from limonitic laterite ores using sulfuric acid. HPAL products include both pure nickel and cobalt metal, as well as Ni chemical compounds such as mixed sulphide (MSP) and hydroxide precipitate (MHP) (Crundwell et al. 2011). While all of these products are suitable for high-grade applications, MHP has emerged as the favoured option for further refining into battery cathode materials, and will likely represent the most important new source of nickel for electric vehicle battery manufacturing in the future (Milewski 2021). HPAL products come with a carbon footprint comparable to similar products from sulphide ore processing, far lower than FeNi or NPI (Fukuzawa 2012, Norgate and Jahanshahi 2011, Wei et al. 2020).

Energy and CO2 intensity are highly linked to nickel ore concentration (Norgate and Jahanshahi 2011). Over the past decades, nickel ore grades have declined across the industry and may pose a serious challenge to low-carbon nickel production in the future (Norgate and Jahanshahi 2011, Mudd and Jowitt 2022).

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[2] Improvements and alternatives to HPAL *considered include Enhanced PAL (EPAL), Atmospheric Leaching (AL), and Heap Leaching (HL)*

A considerable risk associated with the growth of HPAL processing is the generation and disposal of hydrometallurgical waste products as by-products, which accrue at around a rate of 1.2t per tonne of ore consumed Fisher and Grossl 2023. This is more waste than for comparable pyrometallurgical laterite and sulphide routes. Local rainfall patterns, topography and seismological activity make storing these products challenging, especially in traditional tailings dams, especially in Southeast Asia, where HPAL is expected to see its greatest boom (Fisher and Grossl 2023, Mudd 2020).

Table 1 - CO2-eq intensity of products sourced according to ore and/or process route

Ore	**Global Warming Potential (t CO2-eq/t of Ni) (Ore Grade)**	**Source**
Laterites (HPAL)	21.4 (1.4%), 22.7 (1.3%), 27.3 (1.3%), *20.1, 24.1, 19.2 (1.35%), 13.9 (1.35%)*	Fukuzawa 2012, Norgate and Jahanshahi 2011, Norgate and Jahanshahi 2011, Fritz et al. 2023, Adiansyah 2023, TMC/Benchmark 2023, TMC/ Benchmark 2023
Laterites (Pyrometallurgy)	102 (1.5%), 18 (2.2%), 45, 41, 30, 63(1.1%), 44 (1.8%), 22.4 (1.3%), 42 (2.4%), 69 (1.88%)	(TMC/ Benchmark 2023), (Wei *et al.* 2020), (Nickel Institute 2020), (Ma 2019), (Nickel Institute/Mistry 2016), Bartzas 2021, (Fukuzawa 2012), Norgate and Jahanshahi 2011, *Norgate 2004, Wei et al. 2020*
Sulphides	*9.15, 14 (2.05%), 8.0 (3.5%), 28.5 (0.6%), 29.2 (0.60%)*	*Fritz et al. 2023, Wei et al. 2020, TMC/ Benchmark 2023, TMC/ Benchmark 2023, TMC/ Benchmark*
Polymetallic Nodules	*6.17 (1.39%), 20.7 (1.39%), 39.1 (1.53%), 37 (1.28%)*	*TMC/ Benchmark 2023, TMC/ Benchmark 2023*, Fritz et al. 2023*, Alvarenga et al. 2022**

An alternative to tailings dams, marine mining waste disposal was banned by the Indonesian government following environmental issues arising from the practice, for example at the Ramu HPAL plant in Papua New Guinea (Mudd 2020, Papua New Guinea Mine Watch 2019, Fisher and Grossl 2023). In its stead, dry stack tailings disposal (Furnell et al. 2022), where waste is neutralised, compacted and used to backfill old mining pits is the most popular solution, albeit a more expensive, and energy intensive technique requiring diligent, ongoing management, particularly so in wetter climates (Fisher and Grossl 2023, Furnell et al. 2022, Nornickel 2023).

Environmental impacts from seabed mining

There is much coverage relating to general lack of understanding of deep sea ecosystems without which assessment of environmental impacts is not possible. However, there is less clarity on what and how much data could be considered to adequately inform decision-making on seabed mining including management measures. There is also little discussion on comparative impacts from different technologies and mining processes and approaches. However, the different types of pollution and other environmental pressures associated with deep sea mining concern both the water column and the seafloor. They can be broadly described as including: habitat removal or alteration, plume burial, plume toxicity, clogging of filter feeders, light pollution, underwater noise, turbidity effects, changed water chemistry and CO2 transfer to the surface waters (Helmons et al. 2022, Washburn et al. 2019), thereby resulting in a variety of ecosystem degradations, some of which may not be recoverable in a human timescale. The body of empirical published research on the pollution and pressure risks expected from deep sea mining activities is introduced below.

Seafloor transformations and associated adverse effects including habitat and biodiversity loss

The seafloor and seamounts where nodule mining and crust mining would take place respectively, will be altered by seabed mining resulting in adverse effects. In addition, an adverse effect of particular concern is the generation of sediment plumes from mining operations, e.g. by nodule collectors and (crust) rock-cutting machines (Helmons et al. 2022), although questions remain on plumes' behaviour, their extent, reach and effects on different organisms, proximity to mining operations being an important factor but not the only one (Jones et al. 2017, Muñoz-Royo et al. 2022, Gillard et al. 2019). A frequently mentioned process concerns the redeposition of stirred up sediments on benthic communities, risking burying them and e.g. particularly affecting suspension feeders. This process is expected to extend much beyond mining sites (Helmons et al. 2022, Drazen et al. 2019). Assessments of impact studies show that the local diversity of species declines at locations where mining tests took place or were simulated (Jones et al. 2017). Further, because nodules provide a hard substrate for species to settle on, their removal means permanent localised habitat removal (Jones et al. 2017). This threatens local endemic species, for example deep sea nematodes with extinction (Danovaro and Gambi 2022). Furthermore, slow ecosystem processes due to low temperatures and high pressure, translates in slow habitat recovery, if any, from sediment deposition and removal of nodules, with assessments reaching millions of years (Jones et al. 2017).

Studies of impacts from seabed mining activities tend to focus on nodule mining with far less studies considering effects of crusts and sulphide extraction (Spearman et al. 2020). Spearman et al.'s estimate of the extent of the benthic plume from crust extraction reaches 1.4 km from the mining site (using a threshold value of 0.01 mg/l). The rich biodiversity, habitat complexity and generally high species' endemism of seamounts result in their particular vulnerability and a characterised risk of biodiversity loss in case of mining that would in effect result in full habitat, if not local ecosystem removal (EASAC 2023).

Effects from extraction and processing, including greenhouse gas emissions and pollution

Other potential impacts from extraction and processing include the emission of greenhouse gases (GHG), polluting substances, as well as light and noise. First, GHG emissions are generated by operations of support and transport vessels used for nodule, crust and sulphide mining. GHGs emitted through the use of heavy fuel oil used by vessels include carbon dioxide and methane (Heinrich et al. 2020). A study by Heinrich et al. (2020) estimated that commercial nodule mining in the Clarion Clipperton Zone, depending for example on the destination, engine loads and specific fuel used, contributes 82,600 - 482,000 t CO2-equivalent per year. There are also claims that some carbon would be released during polymetallic nodule mining. Secondly, for seabed mineral extraction methods, there is a risk of metal release into the water, e.g. through dewatering processes at the surface vessel. Depending on their point of entry into the water column, the physiology and behaviour of different organisms would be exposed to their release, with a risk of bioaccumulation across the food chain (Hauton et al. 2017). Third, and in addition, other adverse effects concern light, noise and vibrations generated by *inter alia* the nodule collector, the riser pipe that pumps up nodules and discharges water, and the sonars of ships (Williams et al. 2022). Williams et al. (2022) modelled the noise produced by mining operations and estimated that mining noise that exceeds ambient noise would extend to approximately 500 km. Light, noise and vibration are recognised sources of (potentially lethal) threats to birds and marine species by e.g. interfering with their communication, feeding, reproduction and more generally navigation. (EASAC 2023, Drazen et al. 2019).

Who?

This section focuses on key players in terrestrial nickel production (mining and refining) and key players in deep seabed mining activities (exploration only at this stage), including countries and known private or public entities involved. Key players in terrestrial mining activities were selected on the basis of the following factors: (i) size of nickel reserves under their jurisdiction; and (ii) contribution to global production, as evidenced in publicly available material. Considering that deep seabed mining activities are still limited to exploration, key players were identified based on their known commercial interest in deep seabed mining and their current exploration activities. They include (i) countries with an exploration contract with the ISA, (ii) those engaged in exploration activities within their EEZ, (iii) other states that have made their position on the prospects of exploitation known only at this stage, and (iv) private or public entities involved. High level findings are summarised in Table 2 below that compares key players in terrestrial and seabed mining activities, noting that some countries belong to both categories. It investigates e.g. *potential* interlinkages between the economics of nickel mining including the access to resources of a country and their position in the seabed mining moratorium discussion.

Key players in terrestrial nickel mining and refining

As of 2023, the Chinese firm Tsingshan controlled a fifth of global primary nickel production, primarily through its extensive mining and processing operations in Indonesia. Chinese groups Delong and Jinchuan are the second and third largest producers, respectively, accounting for a combined 16% of global production. In fourth place was Russian miner Nornickel, also the world's leading producer of high-grade nickel, Swiss trader-miner Glencore, Brazilian miner Vale, CNGR, Zoomwe, Shandong Xinhai, Huayou, and Lygend. Together, all of these firms combined for 62% of global primary nickel production. Chinese-based firms accounted for at least 49% of the world's output (Nornickel 2023). The global high-grade production market is highly concentrated but geographically dispersed, with the ten largest producers accounting for around 90% of the market. Top producers here are Nornickel, Jinchuan, Glencore, Vale, Japanese firm Sumitomo Metal Mining, Australian giant BHP, Sumitomo Corp., Huayou, Canadian company Sherritt, and UK-based Anglo American (Nornickel 2023).

The traditional approach between primarily low-grade producers (in China for steel) and high-grade producers (in the west for higher end uses) has been eroded through novel market dynamics driven by a number of direct and indirect shifts and developments. These include (i) the fast development of nickel extraction from laterites in Indonesia; (ii) large-scale Chinese investments processing capacity (in Indonesia) leading to a dominant position for Chinese firms in this market (Wood Mackenzie 2023); (iii) Chinese firms' subsequent success in deploying cost-effective novel HPAL processing plants for the production of higher-grade nickel products from laterites; and, (iv) the rise of NPI-to-matte conversion in response to NPI market surpluses.

More recently, many producers outside of Indonesia have faced issues from persistently depressed nickel prices, caused in part by NPI oversupply, further worsened by declining ore grades and their associated market value. Some have been forced to suspend operations entirely, others have seen routine operational difficulties exacerbated. Increasingly, low prices are also putting projects in Indonesia under pressure, with reports of delays and cancellations of planned operations
The challenging price environment is also worsening unresolved social issues associated with operating practices in traditional mining strongholds (e.g.social unrest in New Caledonia in 2024 more generally, Golubkova and Obayashi 2024, Trompiz 2024).

Finally, new entrants have surged into Indonesia to capitalize on the growing nickel market. Among these are Indonesian entities and multinational corporations seeking to secure raw materials supplies for their supply chains. Notable players here are Ford Motors, CATL, Gotion, LG, and Hyundai (Ford 2023, Syahtra 2023, Nangoy and Sulaiman 2023), Ruehl 2023).

Key players in seabed mining operations

Although currently there is no commercial exploitation of deep seabed mineral deposits, a diversity of private and government-owned entities are interested in the mining of different seabed mineral deposits, especially polymetallic nodules, found within (continental shelf including the extended continental shelf) or outside national jurisdiction (the Area). So far, only exploration permits have been granted, whether beyond or within national jurisdiction. There has been no application for exploitation permits yet though The Metals Company (TMC) has announced an application for PMN mining in the Clarion Clipperton Zone in July 2025 (TMC 2024).

Organisations pursuing deep seabed mining exploration activities come from a wide range of backgrounds, with different priorities and interests in these activities. Three broad types of operators and contractors and associated interests can be distinguished:

(1) public contractors representing national governments, or acting on their behalf, focused primarily on research activities with no known intention to proceed to commercial mineral exploitation nor engage in mining activity developments (e.g. governments of France and Germany,

represented by the contractors IFREMER, and the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR). Most of them have been involved since the 70s or 80s.

(2) public and state-owned contractors for whom the sourcing of critical energy transition raw materials may represent a matter of national interest and security, and who are actively developing technologies related to exploration and exploitation activities. Notable examples include the Chinese, South Korean, Indian, and Japanese governments.

(3) private companies, which are interested in the commercial exploitation of seabed minerals. For example these include (formerly) Nautilus Minerals Inc. (Canada)/ Deep Sea Mining Finance (DSMF) in the EEZ of Papua New Guinea, TMC (also incorporated in Canada and linked to Nautilus Minerals Inc, and formerly known as DeepGreen) in the Clarion Clipperton Zone, the Belgian Global Seabed Resources (GSR) in the Clarion Clipperton Zone and the EEZ of the Cook Islands, the Norwegian company Loke Marine Minerals (which acquired the UK Seabed Resources from Lockheed Martin (USA) (Doherty 2019, Marais 2018, Nangoy and Sulaiman 2023, DEME GSR 2021), and Green Minerals (DEME GSR 2021, Parlow 2022). These companies rely on the knowledge and expertise of contractors from other maritime industries (oil & gas and dredging). For example, an important partner of TMC is the Dutch/Swiss company Allseas specialised in supply of offshore services to the energy industry. The Belgian GSR, a subsidiary of the Dredging company DEME, partners with the US/Swiss company Transocean Ltd. (Allseas 2021, DEME GSR 2023).

Table 2 - Key players in exploration and exploitation activities for nickel resources

Countries that are not generally recognised as holding potentially commercially viable deposits are not included. **Colour legend** available in the caption to figure 1. The column on nickel reserves and/or production relies on USGS Mineral Commodities Review (2025). Supporting evidence for this table to be found in the Bibliography.

Acronyms: Global Mineral Resources (GSR); Dredging, Environmental and Marine Engineering NV (DEME); The Metals Company (TMC); China Ocean Mineral Resources R&D (COMRA); China Minmetals Corporation(CMC); Beijing Pioneer Hi-tech Development Corporation Ltd. (BPC); Cook Islands Investment Corporation (CIIC); (CIC); French National Institute for Ocean Science and Technology (IFREMER); Federal Institute for Geosciences and Natural Resources (BGR); Deep Ocean Resources Developments (DORD); Japan Organization for Metals and Energy Security (JOGMEG); Pacific Metals Co Ltd (PAMCO); Nauru Ocean Resources (NORI); Interoceanmetal Joint Organization (IOM); Ocean Minerals LLC (OML); Industriële Handels Combinatie (Royal IHC); Korea Institute of Ocean Science and Technology (KIOST); Clarion Clipperton Zone (CCZ); Continental Shelf (CS); Exclusive Economic Zone (EEZ); Polymetallic Nodules (PMN); Cobalt Rich Crusts (CRS); Seafloor Massive Sulfides (SMS); International Seabed Authority (ISA). **Note**: Exploration and exploitation activities for seafloor sulfides are excluded (negligible nickel content).

Country	Nickel reserves and/or production in own country (land/territorial sea & EEZ)	Investment in nickel-related extraction/processing in other countries	Sponsoring state for exploration contract (seabed beyond national jurisdiction)	State-owned/private actors in seabed mining	Interest of seabed mining players	Country position on DSM beyond national jurisdiction
Australia	Holds ~18.3% of global reserves. Canadian mined nickel production accounts for 3% of global output.	Nickel Industries, First Quantum - miners with interests in Indonesian nickel mining.	No	*Neptune Minerals (v.1)	SMS mining in New Zealand's EEZ.	No declared position
Belgium	None	Chemical engineering, metallurgy, and recycling company Umicore is headquartered in Belgium	Yes	DEME-GSR	DEME-GSR (1) explores the seafloor for PMNs in the CCZ, and the Cook Islands EEZ (subsidiary CIIC), (2) develops and tests nodule collector mining equipment.	No declared position but ongoing exploration in the CCZ and Cook Islands CS
Brazil	~12.2% of global reserves. Production accounts for approx. 2% of the global total	Vale mines Ni in Indonesia, Canada, and Brazil. JV investment in Indonesian HPAL & RKEF projects	No* (Contract Cancelled)	No	n/a	Precautionary Pause until sufficient scientific evidence is available, and regulations, standards and guidelines are adopted by the ISA.
Canada	Holds 1.7% of global land based reserves. Projects account for 5.2% of global mine production.	Sherritt International co-operates the Moa Bay nickel mine and HPAL project in	No	TMC	TMC is a Canadian-based DSM company that targets polymetallic nodule mining in three licence areas	Moratorium until 'rigorous regulatory structure that protects the marine environment is in place' a

Country	Nickel reserves and/or production in own country (land/territorial sea & EEZ)	Investment in nickel-related extraction/processing in other countries	Sponsoring state for exploration contract (seabed beyond national jurisdiction)	State-owned/private actors in seabed mining	Interest of seabed mining players	Country position on DSM beyond national jurisdiction
	Home to significant processing and refining operations.	Cuba.			of Nauru, Tonga and Kiribati in the CCZ.	'comprehensive understanding of the environmental impacts of [DSM]'.
China	Holds 3.4% of global land-based reserves, and an estimated 3.3% of global mine production. Significant producer of refined nickel products.	Chinese companies such as Tsingshan are heavily invested in Indonesian mines & local RKEF and HPAL facilities. Major Chinese firms account for ~37% of global Ni output.	Yes	COMRA, CMC, BPC, Jinhang Group, Soil Machine Dynamics.	Pioneer investor. State-owned companies COMRA, CMC and BPC continue research, exploration and development and testing of mining equipment in Contract areas in the CCZ and the Western Pacific Ocean.	No declared position but active DSM exploration, mining tests
Cook Islands	Explore PMN in EEZ. The government partners, and issues exploration contracts to CIIC, Moana Minerals and CIC.	None	Yes	CIIC-SR (JV with DEME's GSR), Moana Minerals (US-based subsidiary of OML), CIC (US-based).	Exploration to PMN in Cook Islands EEZ by research institutes and contractors (CIC, Moana Minerals, CIIC-SR).	No declared position but ongoing DSM exploration on CS
France	Nickel refinery at Sandouville. New Caledonia holds 5.4% of global land-based reserves, and accounts for 3% of global mine production.	ERAMET is a major producer of nickel and manganese ore. Eramet operates nickel mines in New Caledonia and Indonesia, where it is also considering a HPAL project.	Yes	IFREMER, TechnipFMC (Franco-US Loke investor)	Pioneer investor. in Group B of ISA Council. IFREMER has an exploration licence in CCZ for PMN and PMS. TechnipFMC develops riser pipe technologies for SMS mining companies such as Nautilus Minerals and JOGMEC.	Ban
Germany	None	BASF showed interest in the Indonesian HPAL project, now cancelled.	Yes	BGR	In Group B of the ISA Council. BGR is a contractor in the Area for PMN and SMS in the CCZ and the Central Indian Ocean. Also partnered with GSR (Belgium) on its "Patania II" mining trial. Planning trials for Impossible Metals' "Eureka III" miner in early 2026.	Precautionary Pause until there is sufficient research on risks, and technologies and operational practices are able to demonstrate that the marine environment is not seriously harmed.
India	Plans to make available its EEZ for seabed mineral exploration, including PMNs.	None	Yes	Ministry of Earth Sciences	Pioneer investor. Exploration contract for PMS and PMN in the Central Indian Ocean.	No declared position but active DSM exploration, including on CS.

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Indonesia	Holds 41.9% of global land based reserves. Source of ~60% of mined nickel in 2024.	None	No	No	n/a	No declared position
Japan	Nickel smelters and refiners in Japan (PAMCO, Sumitomo). Imports mined nickel ores.	Sumitomo Corp. & Sumitomo Metals Mining, investment in mines and HPAL projects in New Caledonia, Philippines, Madagascar, and Australia.	Yes	DORD (PMN contractor), JOGMEC (CRCs), JAMSTEC (REE Muds), The Nippon Foundation (EEZ PMNs), PAMCO signs MoU with TMC for nodule smelting.	Pioneer investor. Public and private. JOGMEC investigates harvesting of SMS, crusts, rare-earth muds and PMNs within national jurisdiction, the Western Pacific Ocean and the CCZ. Nippon Foundation: PMN research for exploitation.	No declared position but active DSM exploration. Planned DSM in own CS.
Kiribati	None	None	Yes	Marawa Research and Exploration Ltd. (former TMC partner)	Sponsoring state to Marawa Research and Exploration Ltd. in the CCZ	No declared position but active DSM exploration
Nauru	None	None	Yes	NORI (TMC subsidiary)	Nauru is sponsoring state to NORI in the CCZ.	Ongoing DSM exploration in CCZ, mining tests. Application to ISA for exploitation announced for July 2025.
The Netherlands	None	None	No	Boskalis Westminster (CIC investor), IHC (EU DSM programs), Allseas (TMC investor, BMJ owner),	Dutch-based companies develop and test seabed mining equipment for PMN and SMS. Boskalis invests and collaborates with CIC in the Cook Islands and with Impossible Metals (US-based) for transportation of nodules. Allseas invests and collaborates with TMC in the CCZ. IHC develops mining equipment for SMS and PMN.	No declared position
Norway	Norway has opened its continental shelf to CRC & SMS mining. Hosts Glencore's Nikkelverk smelter.	None	No	Loke Minerals (PMNs CCZ, CRCs EEZ), Green Minerals (PMNs* CCZ), Adepth Minerals	Exploration SMS mining in its own CCZ Named companies collaboratively explore Norway's continental shelf in the EMINENT	No declared position but ongoing DSM exploration on own CCZ with a process deferral for further development.

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				(Norway EEZ), Kongsberg, Wilhelmsen Gruppens.	project.	
Poland	Minor nickel sulfate production by KGHM.	KGHM is developing a nickel mine in the Sudbury area, Canada.	Yes	Interoceanmetal Joint Organisation (IOM) (Joint sponsorship with Russia, Czech Republic, Slovakia, Bulgaria, Cuba)	IOM is an ISA contractor exploring for PMNs in the CCZ.	No declared position but ongoing DSM exploration in CCZ
Philippines	Holds 11.1% of global terrestrial reserves. Philippine mines accounted for 3.7% of global production in 2025	No	No	NA	NA	No declared position
Republic of Korea	No reserves or domestic mine production. Battery manufacturing & recycling hub.	Hyundai & LG investment in EV battery supply chain in Indonesia.	Yes	Ministry for Oceans and Fisheries. Works with e.g. KIOST who tested Mining Robots: MineRo I and MineRo II.	Large investor in DSM and is part of Group B of the ISA Council.	No declared position but ongoing DSM exploration in CCZ and Indian Ocean
Russian Federation	Holds 6.3% of global land based reserves, and accounts for 5.7% of global mined production. Largest producer of high-grade nickel.	Nornickel has a nickel processing plant in Finland through their subsidiary Norilsk nickel Harjavalta.	Yes	JSC Yuzhmorgeologiya, Ministry of Natural Resources and Environment. Participates also in the Interoceanmetal Joint Organization (IOM) ISA contractor, together with Poland, the Czech Republic, Slovakia, Cuba, and Bulgaria.	Pioneer investor. Active resource definition and metallurgy work, but progress towards exploitation is not apparent. No final decision to proceed.	No declared position but ongoing DSM exploration in CCZ
South Africa	One of the largest nickel producing countries of Africa. Sibanye-Stillwater and Impala Platinum exploit nickel deposits	Sibanye-Stillwater exploring involvement with PRONY HPAL in New Caledonia. Sibanye owns Sandouville	No	No	n/a	No declared position

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	in South Africa.	nickel refinery in France.				
Sweden	Canadian company Gungnir is actively drilling for land-based nickel reserves.	Boliden operates the Kevitsa mine and Harjavalta refinery/smelter in Finland.	No	No	n/a	Precautionary pause until sufficient scientific evidence is available, and regulations, standards and guidelines are adopted by the ISA.
Tonga	No	No	Yes	Tonga Offshore Mining Limited (TOML)	TOML (TMC subsidiary) holds an ISA exploration contract for PMNs in CCZ	No declared position,
United States of America	Small amount of domestic nickel deposits and production. One remaining nickel mining operation, Lundin's Eagle Mine operation.	None	No	Odyssey Exploration, ERAS Holdings (Karkar Family behind TMC), Ocean Minerals LLC (Cook Islands contractor), CIC, Oil States Industries (RiserTec owner), Transocean (Investor with OML, GSR), Impossible Metals (Equipment developer, contractor*),	TMC indicated that it would seek a mining permit for exploitation under the existing US mining code. Odyssey Exploration holds an interest in Ocean Minerals LLC and is consortium member for CIC. Ocean Minerals LLC and CIC have subsidiaries that explore the seabed for PMN in the Cook Islands and the CCZ; ERAS Holdings invests in TMC; Oil States Industries' independent division Risertec develops riser technologies. Impossible Metals (US/Canadian based) launched a mining permit application under US law (outer continental shelf of American Samoa).	Not a party to UNCLOS/1994 Agreement and no declared position otherwise.
The United Kingdom	No reserves. The UK is involved in nickel refining processes through Vale.	Anglo American plc mines nickel in Brazil; Partnership with South Africa for nickel exploration and production.	Yes	Soil Machine Dynamics; Sponsor of UKSRL	UKSRL acquired by Norwegian Loke Minerals, contractor in the CCZ. Soil Machine Dynamics previously developed and built DSM equipment for the Solwara-1 SMS project. Partnered with Green Minerals to develop and build SMS mining	Moratorium until sufficient scientific evidence is available, and regulations, standards and guidelines are adopted by the ISA.

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Country	Nickel reserves and/or production in own country (land/territorial sea & EEZ)	Investment in nickel-related extraction/processing in other countries	Sponsoring state for exploration contract (seabed beyond national jurisdiction)	State-owned/private actors in seabed mining	Interest of seabed mining players	Country position on DSM beyond national jurisdiction
					equipment for future operations in the Norwegian EEZ. Soil Machine Dynamics technology may be relevant for crust mining.	

Table 3 - Countries' interest in nickel production and position on DSM

Countries interest is based on Figure 1 and Table 2. Declared countries' positions are based on public statements on their DSM policy, including research programmes and exploration activities, declarations on test mining, regulatory developments and statements at the ISA. We note that the use and meaning of the concepts of 'precautionary pause' or 'moratorium' varies among countries declared positions on DSM.

Country	Interest in seabed deposits (CS and/or ABNJ)	Interest in terrestrial deposits/ supply chains (in country or abroad)	Declared Country position on DSM beyond national jurisdiction*
France	Yes	yes	Ban
Canada	No	Yes	Moratorium
United Kingdom	Yes	No	Moratorium
Brazil	no	Yes	Precautionary Pause
Dominican Republic	No	Yes	Precautionary Pause
Finland	No	Yes	Precautionary Pause
Greece	No	Yes	Precautionary Pause
Guatemala	No	Yes	Precautionary Pause
Sweden	No	Yes	Precautionary Pause
Germany	Yes	No	Precautionary Pause
Poland	Yes	No	Soft support
Belgium	Yes	Yes	Soft supports
Cook Islands	Yes	Yes	Soft supports
Kiribati	Yes	No	Supports
Nauru	Yes	No	Supports
Norway	Yes	No	Supports
Tonga	Yes	No	Supports
China	Yes	Yes	Supports
India	Yes	Yes	Supports
Japan	Yes	Yes	Supports
Korea (Republic of)	Yes	Yes	Supports
Russian Federation	Yes	Yes	Supports
Australia	No	Yes	Unknown
Philippines	No	Yes	Unknown
South Africa	No	Yes	Unknown
Netherlands (the)	Yes	No	Unknown
Federated States of Micronesia	No	No	Moratorium

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Country	Interest in seabed deposits (CS and/or ABNJ)	Interest in terrestrial deposits/ supply chains (in country or abroad)	Declared Country position on DSM beyond national jurisdiction*
Fiji	No	No	Moratorium
Mexico	No	No	Moratorium
Palau	No	No	Moratorium
Peru	No	No	Moratorium
Samoa	No	No	Moratorium
Switzerland	No	No	Moratorium
New Zealand	No	No	Moratorium (under review)
Austria	no	No	Precautionary Pause
Chile	No	No	Precautionary Pause
Costa Rica	No	No	Precautionary Pause
Denmark (Kingdom of)	No	No	Precautionary Pause
Ecuador	No	No	Precautionary Pause
Honduras	No	No	Precautionary Pause
Ireland	No	No	Precautionary Pause
Malta	No	No	Precautionary Pause
Monaco	No	No	Precautionary Pause
Panama	No	No	Precautionary Pause
Portugal	no	No	Precautionary Pause
Spain	No	No	Precautionary Pause
Tuvalu	No	No	Precautionary Pause
Vanuatu	No	No	Precautionary Pause

* Supports includes support that has been declared or shown and that is implicit or expected from engagement in exploitation investments

Results

Table 2 highlights the parallel and separate existence of the terrestrial and (burgeoning) seabed mining industries. Whereas terrestrial mining is, globally, dominated by private players, the seabed mining network has so far been dominated by public interests due to the nature of the decision-making process at the ISA. However, Table 3 provides some additional insights. Instead of showing a clear link between countries' economic interest in terrestrial mining and DSM, as an interest in securing sources of particular minerals would intuitively play out, it shows four broad categories:

a) countries that have an *interest in both* terrestrial and seabed mining (i.e. generally supportive of DSM, e.g. China, Norway)

b) countries that are *not economically active in either context* and are taking a strong position against DSM. Notably, many countries who have taken a strong position against DSM do not appear to have an interest in terrestrial mining; except France (with a ban), Canada and the UK (moratorium). c) countries with an interest in seabed mining but *not* in terrestrial mining and no resource within national jurisdiction (e.g. Nauru); and

d) countries that have an interest in terrestrial mining and not in seabed mining; these can be further divided: those who want a moratorium or precautionary pause on DSM (e.g. Brazil, Finland) and those that are undecided (e.g. Australia and South Africa).

Furthermore, tables 2 and 3, and the accompanying map (figure 1), show that two key countries in land-based mining production of nickel also actively explore deep sea minerals in areas beyond national jurisdiction: China and Russia. However, the other countries with large reserves are not (Australia, Brazil, Canada, Indonesia, Philippines), except France (noting that land reserves are located in New Caledonia - a semi-autonomous French territory, and that substantial French investments have been made to secure nickel from Indonesia). Another growing category is that of countries who value nickel resources within national jurisdiction, on their continental shelf (e.g. Cook Island, Nauru, Kiribati, Tonga, Norway). In addition, other countries without known reserves within national jurisdiction have made important investments to secure access to terrestrial nickel supply (e.g. in Indonesia, by China, France, Japan and South Korea, and in the Philippines and Madagascar by Japan). Nevertheless, 80% of the countries who made a statement supporting a 'moratorium' do not have such a known economic interest. Similarly, ⅔ of the countries that declared a precautionary pause do not either.

Where this investigation landed

Terrestrial vs seabed sources- Accessibility to and extractability of mineral resources always come with constraints and trade-offs. Other constraints relate to processing, energy and water intensity, political and social context. As is highlighted by environmental scientists themselves, the decision to prioritise different resources is necessarily a political decision that goes beyond scientific findings to take into account societal, economic and geopolitical dimensions. They also highlight the challenges in comparing adverse environmental effects of land and seabed mineral mining due to their lack of comparability. However, by identifying the consequences of difference prioritisation, environmental science must inform decisions on limits of acceptability.

Ecological impact- Metaxas et al. (2024) point to fundamental differences of land vs. seabed environments that make for a somewhat unreasonable 'natural science' assessment. For example, it is not useful to compare biodiversity as a numerical indicator on land with biodiversity on the deep seabed, due to the differences in the functions of that biodiversity in each ecosystem. In any case, serious ecological impacts (high biodiversity and ecologically sensitive areas) are involved with the extraction of land and seabed mineral resources though restoration, and therefore reversibility may be easier or more feasible on land (subject to social and political context). Indicators suggested by Metaxas et al. include a comparison of scale of impacts, offsite impacts, and cumulative impacts. What other objective criteria could guide extraction decisions?

Climate impact- Energy, water, and carbon intensity as well as GHG emissions from mineral extraction and processing is seldom discussed and seem to only have a moderate influence over investment and sourcing decisions, compared to cost considerations. The rise in conversion of Indonesian Nickel Pig Iron (NPI) to sulfide matte suitable for use in electric vehicle battery production increasingly replaces sulfide, and laterite HPAL nickel products, which are less carbon intensive compared to NPI. Proposed DSM-sourced nickel, higher grades, and the coextraction of other metals would, in general, result in carbon intensities comparable to sulfide and HPAL routes, beating out NPI (table 1).

Players- The main non-country actors in the seabed mining network are different from those in the land mining network. For now the global land-mining industrial players have mostly remained outside the seabed mining debate. They appear to not be directly engaging in discussions on the terms that should apply to the exploitation of seabed minerals, or even whether it should go ahead at all. Yet this debate considers seabed mineral resources in the context of a global demand for these resources. But how can a discussion on the global demand and supply of a mineral progress if key suppliers do not partake? Is it even a global demand and supply issue?

Societal need- Directly Linked to this global demand, its projection depends on future scenarios that diverge greatly between the views of the industry and that of the ENGOs. Key parameters of this divergence include the short and long term evolution of battery chemistries, the scalability of novel, less mineral demanding technologies' applicability to different uses, and the time-horizon for the development of a recycling market for minerals concerned.

International politics- Geopolitical tensions and global politics are pushing countries to decrease their dependance on countries perceived as having antagonistic interests, and to diversify their raw materials supply chains. Seabed mineral resources can therefore become particularly relevant to countries without access to terrestrial supplies of raw materials. Technical and financial resources needed, however, demand considerable resource mobilisation from interested countries which can then become barriers to entry.

Possible outcomes- Adequate consideration of the climate and biodiversity crises should be a key driver of future policies. However, the complex interplay between the many discourses and forces at play (e.g. demand for development and for the energy transition, the development of the Blue Economy, geopolitics, critical mineral vs triple plenary crisis, social licence to mine) makes it challenging.

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Table 2 List of supporting evidence

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