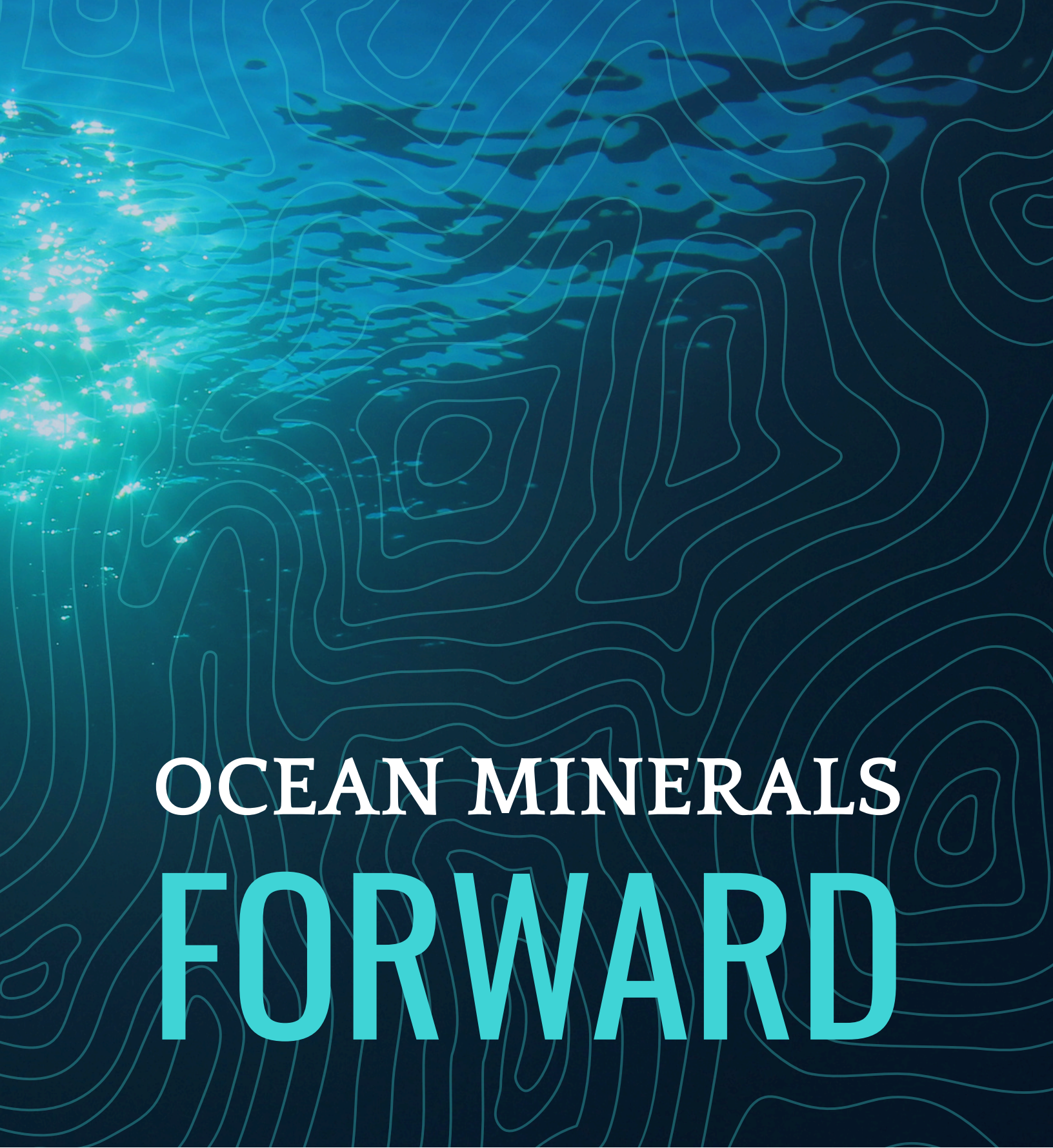




# OCEAN MINERALS FORWARD

OCTOBER 2026

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# Below the Surface: Securing America's Industrial Future from the Seafloor Up

The minerals helping to drive the modern economy, like copper, nickel, cobalt, manganese, and rare earth elements, are inside every electric vehicle, data center, weapons platform, and power grid being built today, in ever rising quantities. And the world is running short of secure access to them.

Global demand is compounding, driven simultaneously by electrification, AI infrastructure, defense modernization, and the industrialization of economies that haven't finished developing. The World Bank projects critical mineral demand to grow 500 percent by 2050.<sup>1</sup> The supply side has not kept up, and the gap is structural. Ore grades are declining across major mining districts worldwide.<sup>2</sup> A new mine in the United States averages 29 years from discovery to first production.<sup>3</sup>

The seafloor has moved from scientific curiosity to industrial priority for a simple reason: The minerals the global economy cannot find enough of on land exist on the seafloor in concentrations that, in some cases, exceed all known terrestrial reserves combined.

The United States built its industrial strength on a premise that has quietly lost influence: Access to raw materials was never someone else's problem to solve. Iron from Minnesota fed the steel mills. Coal from Appalachia powered the railroads. Oil from Texas and the Gulf of America fueled a century of growth. Materials sovereignty and economic sovereignty were understood to be the same thing.

That's no longer where we are. The cobalt in fighter jet components, the nickel in battery packs, the rare earth elements in missile guidance systems, none of it comes from American soil in any meaningful quantity. It comes from supply chains the United States does not control, shaped by a country that has demonstrated it will use that position when it suits them.

China banned rare earth exports to Japan in 2010 over a fishing dispute. It restricted gallium and germanium exports in 2023. In December 2024 it imposed a full export ban on critical materials to the United States, and by October 2025 had gone further — targeting rare earth magnet controls directly at U.S. defense supply chains. An F-35 contains over 900 pounds of

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<sup>1</sup> <https://www.worldbank.org/en/news/press-release/2020/05/11/mineral-production-to-soar-as-demand-for-clean-energy-increases>

<sup>2</sup> <https://substack.com/home/post/p-197963221>

<sup>3</sup> <https://press.spglobal.com/2024-07-18-United-States-Ranks-Next-to-Last-in-Development-Time-for-New-Mines-that-Produce-Critical-Minerals-for-Energy-Transition.-S-P-Global-Finds>

rare earth elements. A Virginia-class submarine requires around 9,200 pounds. There is currently no heavy rare earth separation happening on American soil. Each restriction follows the same logic: find a dependency, apply pressure, wait.




## 2025 List of Critical Minerals

|                             |                                 |                                |
|-----------------------------|---------------------------------|--------------------------------|
| <b>60</b> CRITICAL MINERALS | <b>10</b> NEW CRITICAL MINERALS | <b>15</b> RARE EARTH ELEMENTS* |
|-----------------------------|---------------------------------|--------------------------------|

|             |                    |            |
|-------------|--------------------|------------|
| ALUMINUM    | HAFNIUM            | RHODIUM    |
| ANTIMONY    | HOLMIUM*           | RUBIDIUM   |
| ARSENIC     | INDIUM             | RUTHENIUM  |
| BARITE      | IRIDIUM            | SAMARIUM*  |
| BERYLLIUM   | LANTHANUM*         | SCANDIUM   |
| BISMUTH     | LEAD               | SILICON    |
| BORON       | LITHIUM            | SILVER     |
| CERIUM*     | LUTETIUM*          | TANTALUM   |
| CESIUM      | MAGNESIUM          | TELLURIUM  |
| CHROMIUM    | MANGANESE          | TERBIUM*   |
| COBALT      | METALLURGICAL COAL | THULIUM*   |
| COPPER      | NEODYMIUM*         | TIN        |
| DYSPROSIUM* | NICKEL             | TITANIUM   |
| ERBIUM*     | NIOBIUM            | TUNGSTEN   |
| EUROPIUM*   | PALLADIUM          | URANIUM    |
| FLUORSPAR   | PHOSPHATE          | VANADIUM   |
| GADOLINIUM* | PLATINUM           | YTTERBIUM* |
| GALLIUM     | POTASH             | YTTRIUM*   |
| GERMANIUM   | PRASEODYMIUM*      | ZINC       |
| GRAPHITE    | RHENIUM            | ZIRCONIUM  |

U.S. Department of the Interior  
U.S. Geological Survey

Learn More  
[www.usgs.gov](https://www.usgs.gov)

Source: <https://www.usgs.gov/programs/mineral-resources-program/science/about-2025-list-critical-minerals#CurrentStatus>

The seafloor offers a different answer, and one closer to production than most people realize. The technology to collect polymetallic nodules has been tested in the field. The regulatory path is active and improving. American industry has the offshore engineering expertise, the vessel infrastructure, and the workforce to lead, much of it proven across decades of deepwater operations in the Gulf of America.

# What Lies Beneath

Geologists have known for decades that the seafloor holds more of certain metals than all of the world's land-based mines combined. Nickel resources in Clarion-Clipperton Zone (CCZ) nodules and Prime Crust Zone cobalt crusts alone come to 306 million metric tons against global land reserves of 95 million. Cobalt: 94 million metric tons offshore against 7.5 million on land. Manganese: 7,706 million metric tons under the ocean against 1,504 million in every known terrestrial deposit on Earth.<sup>4</sup>

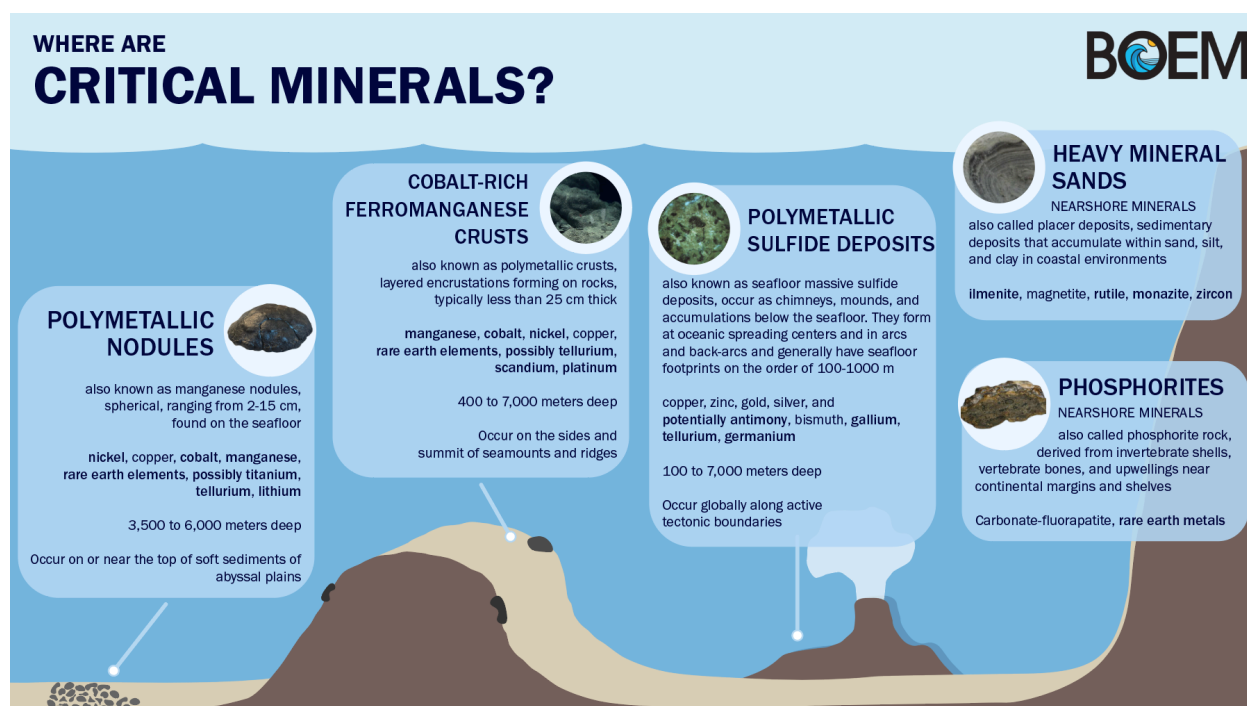


Image source: <https://www.boem.gov/marine-minerals/critical-minerals/types-relevant-marine-mineral-deposits>

The United States is managing a critical minerals crisis while sitting at the edge of an ocean that contains multiples of what the land can supply.

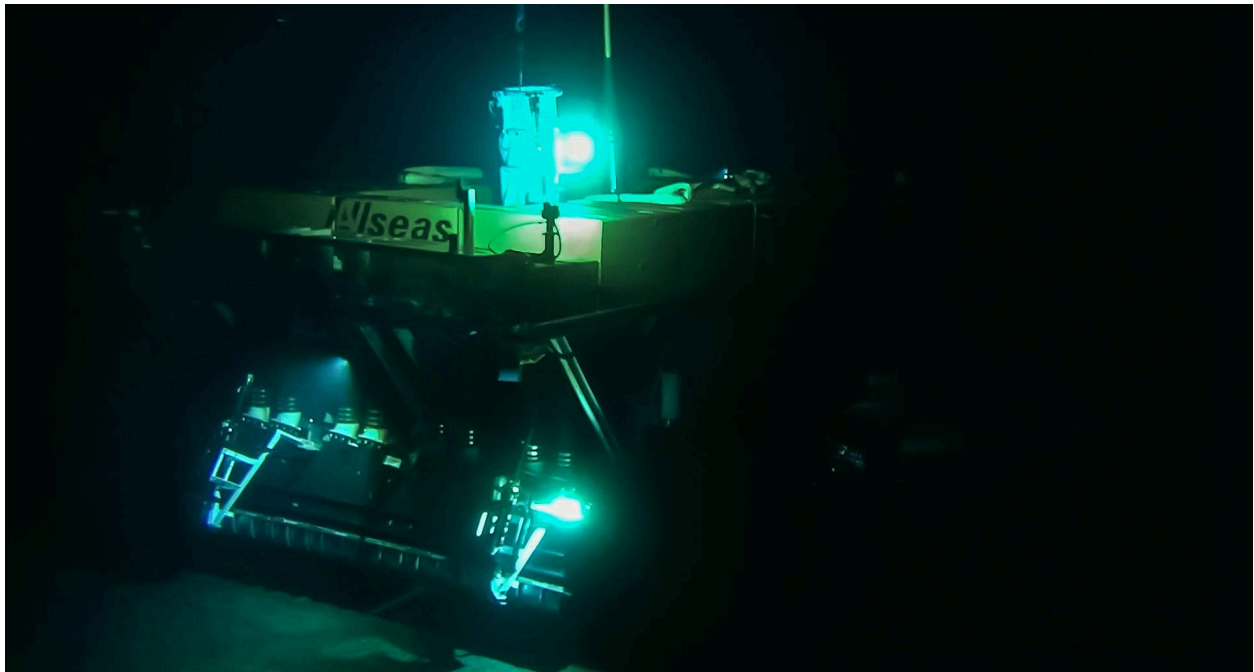
The Marine Minerals Administration (MMA) has mapped five distinct mineral systems on and beyond the Outer Continental Shelf (OCS)<sup>5</sup>, each formed by different geological settings, sitting at different depths, carrying a different metal spectrum, and presenting different engineering and environmental considerations. Collapsing them under the shorthand of "deep-sea mining"

<sup>4</sup> <https://static01.nyt.com/newsgraphics/documenttools/01228b416fb7ca7d/889da0f3-full.pdf>

<sup>5</sup> <https://www.boem.gov/factsheet/americas-offshore-critical-mineralsresources>

obscures both the scale of what's available and the range of options for developing it responsibly.

The five deposit types are not equally mature or equally suited to near-term development. Polymetallic nodules and ferromanganese crusts have the most advanced exploration, characterization, and permitting track records. Heavy mineral sands offer the most accessible near-term domestic and fastest production pathway. Seafloor massive sulfides and phosphorites sit in different strategic and regulatory categories. Treating them as interchangeable produces policy arguments that fit none of them accurately.



*Source: Allseas/The Metals Company*

Collection architectures for nodules vary. In the approach drawn most directly from offshore energy practice, a collector vehicle works the nodule field on the seafloor and a riser pipeline lifts material to the surface vessel. No component required invention from scratch. Vessels, riser systems, ROVs, subsea sensors, dynamic positioning, hydraulic pumps – all of it has decades of commercial deployment in offshore energy. In a second approach, fleets of autonomous underwater robots hover above the seafloor, select individual nodules, and return to the surface under their own buoyancy, with no riser, no seafloor contact, and no return-water discharge. Nodule collector vehicles have demonstrated recovery of thousands of tons at full water depth. Autonomous underwater robots have demonstrated small-scale recovery in shallower waters (~1,800m) with full depth trials expected in 2028.

The other deposit types call for different tools. Heavy mineral sands, for example, sit in shallow nearshore water and are dredged with the same trailing suction and cutterhead equipment that's moved sand and gravel for coastal construction for a century, while ferromanganese crusts, seafloor sulfides, and phosphorites each demand their own variation on cutting, shearing, or hybrid dredging systems suited to the hardness and depth of the host rock.

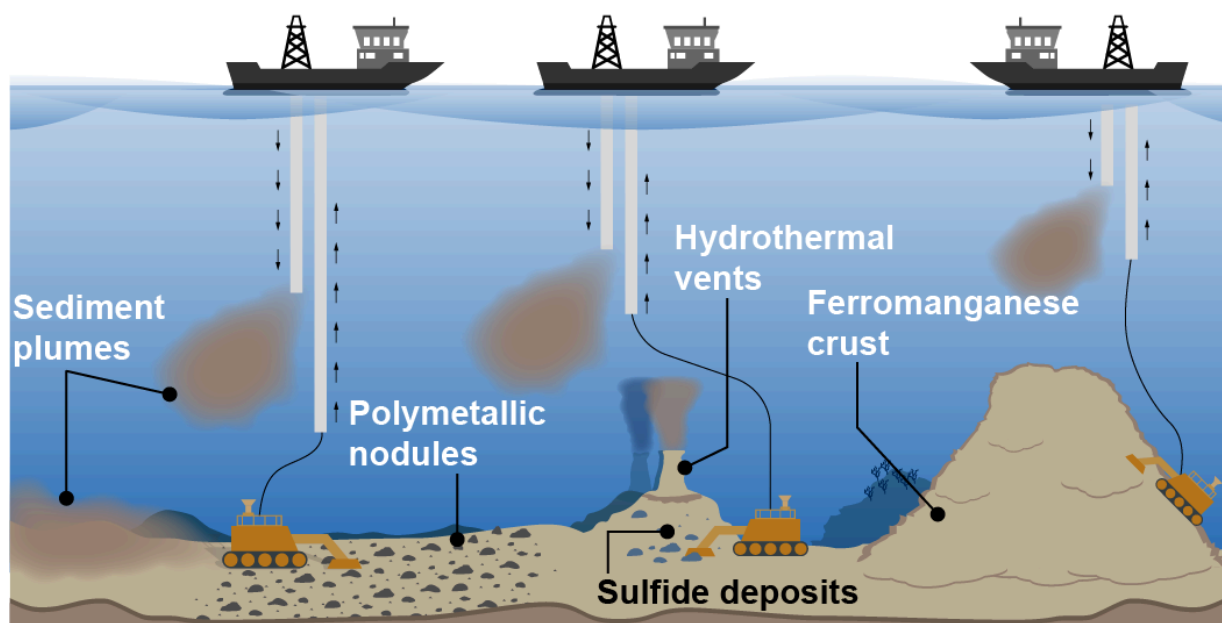


Image Source: <https://www.gao.gov/products/gao-22-105507>

America's offshore mineral resources cover defense metals, battery metals, fertilizer minerals, and rare earth elements. The United States has jurisdiction over, or treaty-based access to, meaningful portions of all of it. Developing that portfolio with the right technology matched to the right deposit type, under American regulatory standards, is well within U.S. industrial capacity.

## BREAKOUT

### *One Resource, Multiple Metals*

The seafloor holds five resource types with commercial potential — nodules, crusts, seafloor massive sulfides, heavy mineral sands, and rare-earth muds — but three of them account for nearly all of the exploration activity and development underway today.

#### POLYMETALLIC NODULES

Metals: Manganese · Nickel · Copper · Cobalt · Rare Earth Elements

Depth: 4,000–5,500 m · Abyssal Plain

Discrete rocks, 2 to 30 centimeters in diameter, sitting unattached on the abyssal plain. They form when dissolved metal compounds precipitate out of seawater and accumulate in concentric layers around a nucleus, typically a shark's tooth or a rock fragment. Growth rates run between 10 and 100 millimeters per million years. A nodule the size of an apple may represent 10 to 20 million years of accumulation.

Because they lie unattached on the seafloor surface, nodules can be gathered without digging, cutting, or blasting, either by low-pressure water jets or by robotic arms that select and lift individual nodules. The abyssal plain is characteristically low-energy and low-food, roughly 10 grams of biomass per square meter, which shapes both the ecological baseline and recovery dynamics after any disturbance.

#### COBALT-RICH FERROMANGANESE CRUSTS

Metals: Cobalt · Nickel · Manganese · Platinum

Depth: 800–2,500 m · Seamount Flanks

Rather than building as free-standing rocks, crusts precipitate as metallic layers 2 to 26 centimeters thick directly onto volcanic rock substrate — growth rates of 1 to 5 millimeters per million years, slower even than nodules. They are commonly associated with seamounts or ridge-flanks involving some level of slope. Unlike nodules, crusts are integral to the seafloor: recovering them requires cutting the ore free from hard rock, a more complex engineering challenge.

The seamount environment is also ecologically distinct. Nutrient-rich currents upwelling along seamount flanks support food webs 10 to 100 times denser in biomass than the abyssal plain, and these features are frequented by tuna and sharks. The environmental calculus for crust development is fundamentally different from nodules, and the industry treats them that way.

### SEAFLOOR MASSIVE SULFIDES

Metals: Copper · Gold · Silver · Zinc

Depth: 1,000–4,000 m · Hydrothermal Vents

Chimney-like mineral structures that form where superheated, mineral-rich water vents through the seabed. Dissolved metals bind into sulfide particles and accumulate into formations that can reach several stories in height. The metal package, such as copper, gold, silver, and zinc, differs substantially from the battery and defense metals found in nodules and crusts.



*Source: Adepth*

Hydrothermal vent ecosystems are among the most scientifically distinctive on Earth, supporting communities of organisms that derive energy from chemical compounds rather than sunlight. These ecosystems are still being characterized by science. Commercial interest in seafloor massive sulfides has moved more slowly than in the other deposit types, and the regulatory picture reflects that earlier stage of development.

All three deposits offer concentrations of metals that land-based mining is increasingly strained to supply. All three sit within regulatory frameworks, domestic and international, that are actively developing. And all three represent resources the United States and its allies have jurisdiction over or access to in quantities that matter for supply chain resilience. Sands and muds carry their own strategic value, the latter in particular for heavy rare earths where China's grip is tightest, but they follow different timelines and different rules, covered elsewhere in this report. The engineering, environmental considerations, and development horizon differ across all five resource types. The strategic case for developing them does not.

## BREAKOUT

### *The Scale of the Seabed Resource Base, and What it Means for U.S. Supply*

The numbers start with a simple comparison.<sup>6</sup> Conservative estimates place the nickel resource in polymetallic nodules at a minimum of 270 million tons globally, exceeding all known terrestrial reserves. Cobalt comes in at a minimum of 44–50 million tons, again exceeding terrestrial totals. Manganese: nearly 42.2 billion tons. These figures come from decades of scientific sampling by the U.S. Geological Survey, the International Seabed Authority, and independent research consortia.<sup>7</sup>

Nodule fields occur across nearly every ocean basin, with the most commercially significant concentrations in the Pacific and Indian Oceans. The Clarion–Clipperton Zone (CCZ), the stretch of the Pacific between Hawaii and Mexico, holds the densest known concentration and has drawn the most sustained scientific and commercial attention, with seventeen parties currently holding eighteen ISA exploration contracts there. The Indian Ocean and South Pacific contain additional fields of significant scale. Exclusive economic zones belonging to the United States and allied nations, like American Samoa, the Northern Mariana Islands, the Cook Islands, Norway, and Japan, contain deposits being actively evaluated under established regulatory frameworks. Recent estimates place roughly one billion tons of nodules in U.S. domestic waters alone and value the seabed mineral resource in a single region of international waters at approximately \$20 trillion.<sup>8</sup> American companies are already positioned in several of the most promising prospective areas.

That geographic distribution is strategically significant. A coordinated strategy across domestic waters, allied EEZs, and international areas can produce a supply that does not depend on any single deposit, any single operator, or any single jurisdiction.

RAND Corporation analysis found that a relatively modest fleet of between three to 20 seabed mining vessels could supply the entire projected U.S. annual demand for cobalt in 2040. For nickel, 11 to 29 vessels could cover projected U.S. demand by the same year.<sup>9</sup>

With the low number of vessels needed, a handful of commercial operators combined could make a substantial contribution to U.S. and allied supply needs within the decade.

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<sup>6</sup> <https://www.sciencedirect.com/science/article/pii/S0959652620338671>

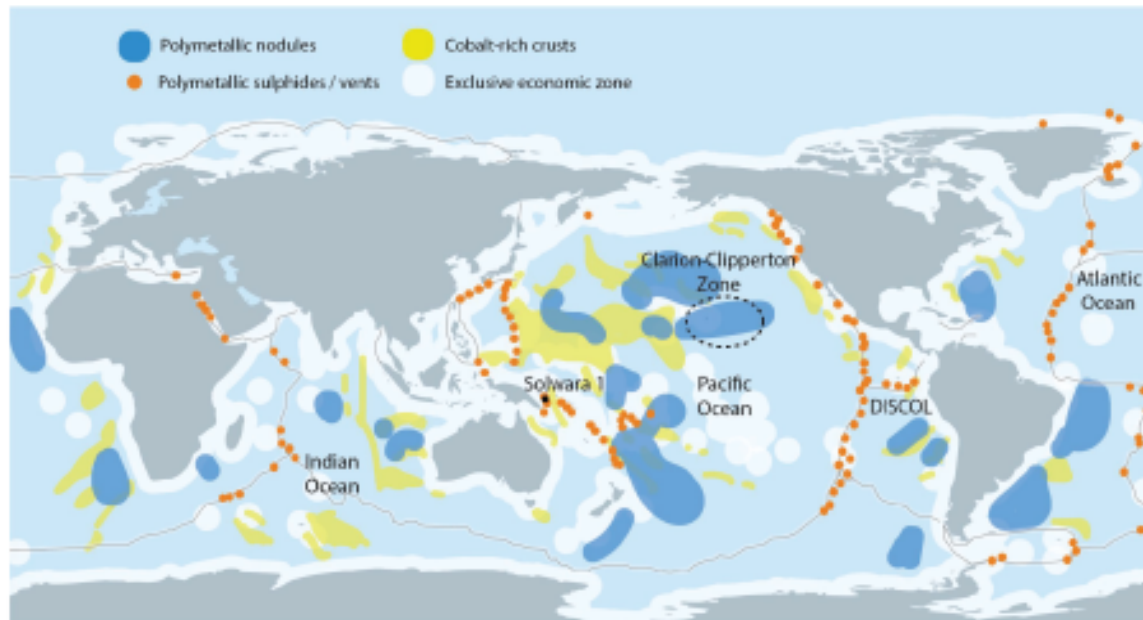
<sup>7</sup> [https://link.springer.com/chapter/10.1007/978-3-030-87982-2\\_3](https://link.springer.com/chapter/10.1007/978-3-030-87982-2_3)

<sup>8</sup>

<https://www.reuters.com/business/energy/trump-expected-sign-deep-sea-mining-executive-order-thursday-sources-2025-04-24/>

<sup>9</sup> [https://www.rand.org/pubs/research\\_reports/RRA3560-1.html](https://www.rand.org/pubs/research_reports/RRA3560-1.html)

## Distribution of critical mineral resources in the deep sea



Note: The white area around Antarctica is not an exclusive economic zone but rather governed by an international commission.

Source: Miller et al. 2018; Hein et al. 2013.

23.0323

 WORLD RESOURCES INSTITUTE

image source: <https://www.wri.org/insights/deep-sea-mining-explained>

North American terrestrial mining, allied-nation production, and recycling programs all contribute meaningfully to the supply base and will continue to do so. However, the World Bank projects global critical mineral demand to grow up to 500 percent by 2050<sup>10</sup>, and greenfield mine development from discovery to production averages 29 years in the United States<sup>11</sup>. No realistic acceleration of terrestrial development closes that gap alone. The seabed resource is what makes a genuinely diversified, resilient supply strategy possible by adding a source of supply at needed scale.

<sup>10</sup> <https://www.worldbank.org/en/news/press-release/2020/05/11/mineral-production-to-soar-as-demand-for-clean-energy-increases>

<sup>11</sup> <https://press.spglobal.com/2024-07-18-United-States-Ranks-Next-to-Last-in-Development-Time-for-New-Mines-that-Produced-Critical-Minerals-for-Energy-Transition,-S-P-Global-Finds>

# From the Glomar Explorer to the Gulf of America

## How Offshore Technology Built the Nodule Industry

The CIA's 1974 operation to recover the sunken Soviet submarine K-129 chose deep-sea nodule mining as its cover story for a reason. A mineral recovery operation required: heavy-lift from depth, a large central well through which equipment could be lowered to the seafloor, and sophisticated positioning systems to hold station in open ocean. Howard Hughes and his Glomar Explorer demonstrated that large-scale mechanical operations were technically achievable. When the vessel lowered a massive claw device on a pipe string to 16,000 feet and grasped a submarine, it demonstrated something the polymetallic nodule industry would build on for the next fifty years: that humans could work precisely at extreme depth, at scale, and with heavy equipment.

What followed was five decades of offshore energy development that built every major technology component a nodule collection system requires, both for robotic-collector or selective harvesting approaches. Throughout the 1970s and 1980s, companies including Lockheed, Kennecott, Rio Tinto,, and international research consortia developed and tested pilot nodule collection systems, while U.S. government programs such as the Deep Ocean Mining Environmental Study (DOMES) program advanced scientific understanding of deep-ocean environments. Although commercial development stalled as metal prices fell and terrestrial supplies remained abundant, the engineering knowledge continued to mature alongside the rapid expansion of the offshore energy sector. Many of the enabling technologies that deep-sea mining now relies upon—including dynamic positioning, subsea robotics, high-strength risers, and deepwater survey systems—became standard tools of the offshore industry over the following decades.

The first approach using robotic collector vehicles and a riser pipe to transport nodules to the surface is built on five well-established technologies:

**Dynamic positioning** — the GPS-integrated thruster systems that keep a drillship fixed over a wellhead regardless of current and weather was developed and refined across thousands of deepwater drilling operations in places like the Gulf of America. A nodule collection vessel uses the same technology to hold station over a seafloor collection area. The engineering is mature, the workforce is trained, and the supply chain exists.

**Riser pipeline** systems that transport material from depth to surface were a core challenge of deepwater oil and gas development going back to the 1970s. Managing the dynamics of a pipe string several miles long was a challenge the offshore energy industry solved commercially, at scale, over decades of production drilling. Nodule collection uses a riser on the same principle: material travels up from a collector vehicle on the seafloor to a surface vessel.

**Remotely operated vehicles** capable of precise work at extreme depth are now routine in offshore energy and marine exploration. Pipeline inspection, wellhead intervention, subsea infrastructure installation – ROVs do all of it, in the dark, at pressures that would destroy an unprotected human, guided by operators on a surface vessel. The collector vehicles that traverse nodule fields are a specialized application of the same technology category, adapted for mineral gathering rather than energy infrastructure.

**Subsea sensing and monitoring technology** developed to track reservoir conditions, wellbore integrity, and seafloor stability in oil and gas operations translates directly to the environmental monitoring requirements of nodule collection, including real-time sediment plume tracking, water column instrumentation, and acoustic seafloor imaging.

**Geophysical survey capabilities** – multibeam sonar, sub-bottom profiling, and acoustic seafloor imaging – were developed to serve offshore energy exploration and is now standard commercial practice across U.S. survey companies. The same tools that locate and characterize hydrocarbon reservoirs locate and characterize nodule fields, map environmental baselines, and generate the data that underpins resource characterization and permit applications.

Dynamic positioning officers, ROV pilots, subsea systems operators, marine engineers, and geophysical surveyors working offshore basins, like the Gulf of America, today, are doing jobs that translate to a nodule mining vessel with comparatively little retraining.

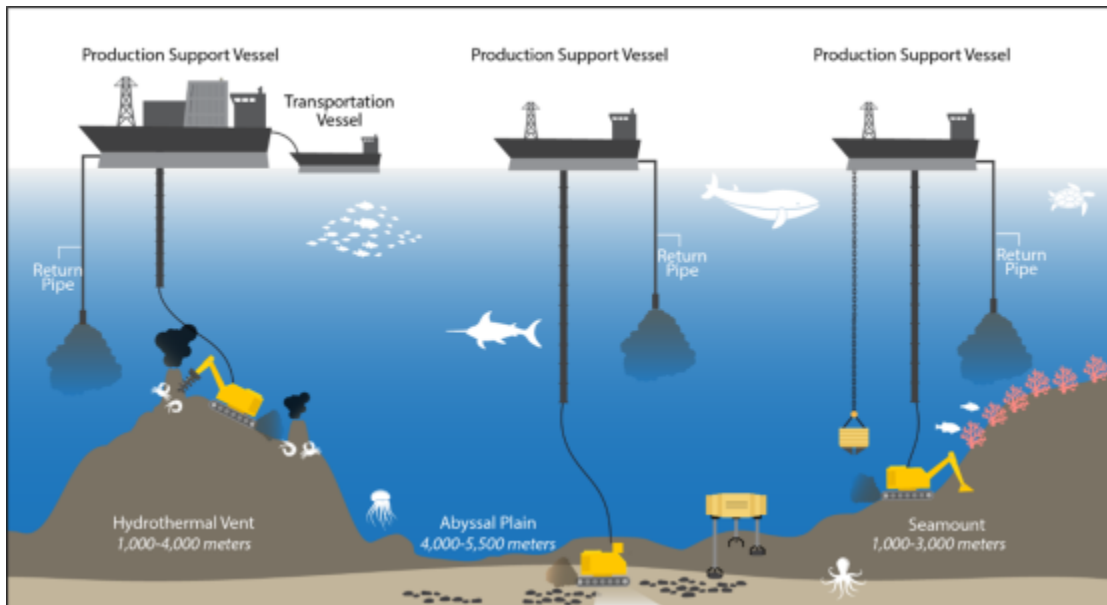
In the selective harvesting approach, which uses a fleet of autonomous underwater vehicles individually picking up nodules and returning them to a single surface ship that retrieves them automatically from the water, technology promises further advances in cost, reliability, and environmental impact. American innovators are pioneering this next-generation approach, providing a potential competitive advantage compared to our geopolitical competitors.

## BREAKOUT

### *From the Surface to Seafloor*

A nodule operation isn't really one vehicle working the seabed. In a collector-and-riser-based operation, it is a stack of assets working the whole water column at once, from the surface ship down to the deepest point of contact three and a half miles below. Selective harvesting distributes those functions differently, but the sensing and monitoring layer described here is common to both.

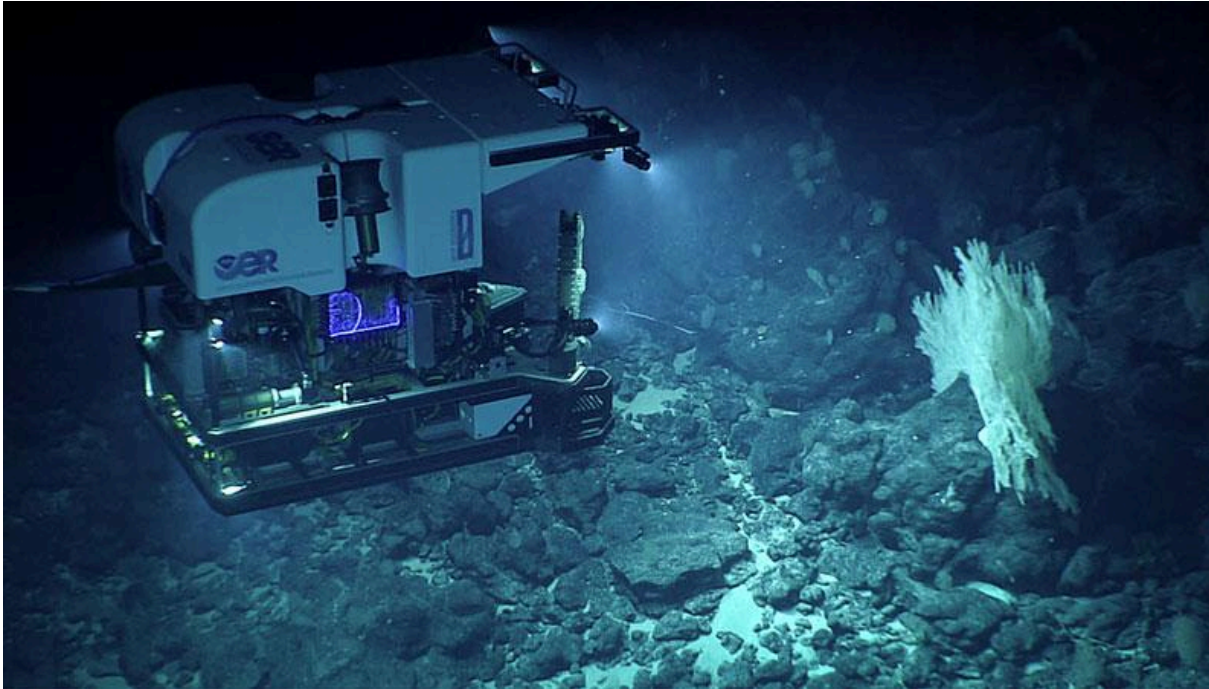
None of these technologies were invented specifically for polymetallic nodule collection. Autonomous underwater vehicles (AUVs), remotely operated vehicles (ROVs), multibeam sonar, acoustic positioning systems, current profilers, and subsea communications are already standard tools in offshore energy, oceanographic research, and commercial marine operations. Nodule recovery brings these mature technologies together into a single integrated system.



Source: [https://www.congress.gov/crs\\_external\\_products/R/HTML/R47324.web.html](https://www.congress.gov/crs_external_products/R/HTML/R47324.web.html)

The surface vessel serves as the operation, hosting the labs, cranes, and positioning systems that launch everything else. From there, autonomous underwater vehicles map the seafloor and track the plume and water-column conditions from above, remotely operated vehicles handle close-up sampling and instrument placement, and seabed landers and moorings sit fixed in place for days and months at a time, recording currents and sediment levels independent of whatever the collector is doing. Collector vehicles and AUVs carry a suite of onboard sensors – current profilers, water-quality probes, cameras – making it as much a monitoring platform as a piece of extraction equipment.

Together, these systems create a continuously updated operational picture that combines navigation, equipment performance, environmental conditions, and scientific observations. Rather than relying on a single instrument or periodic sampling, operators receive information from dozens of interconnected platforms working simultaneously throughout the water column.



Source: <https://oceanexplorer.noaa.gov/technology/subs-deep-discoverer/>

The scale of this is easy to underestimate. During Global Sea Mineral Resources' (GSR, a subsidiary of DEME Group) 2021 Patania II trial, an independent scientific consortium deployed roughly 200 separate instruments across 43 platforms during the initial trial, and a follow-up return visit 18 months later, a sensor network nearly as complex as the mining system it was watching.<sup>12</sup>

Taken together, this tech stack gives companies the potential for a high level of awareness of what's happening below the surface. Operators can observe, in near real time, how disturbed sediment behaves – where it travels, how it disperses, the plume it generates, and how quickly it settles back to the seafloor. That's a different posture than simply complying with a monitoring requirement. It's the ability to understand and adjust a dynamic operation as it's happening, not reconstruct it afterward from samples taken days later.

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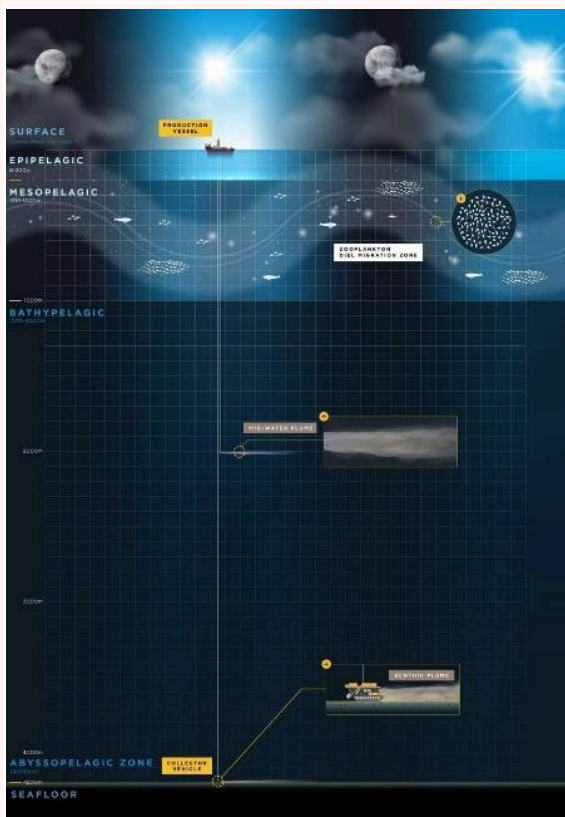
<sup>12</sup> <https://ocean-energyresources.com/2023/03/14/independent-scientific-report-tons-on-gsr-patania-expedition/>

*Engineering From the Seafloor Up: The Metals Company / Innovation at Depth*

Fifty years ago, one of the first deep-sea nodule prototypes used an Archimedes-screw drivetrain to crawl across the abyssal plain, raking up nodules with a rotating head and crushing them on board. It needed deep sinkage for traction, which meant it plowed furrows up to 80 centimeters deep and pulled in so much sticky sediment that the crusher kept clogging.

The Metals Company and Allseas started from a different principle: the Coanda effect, where a jet of water follows a curved surface and generates lift instead of force. Their collector's nozzles hover just above the seabed rather than digging into it, coaxing nodules upward with minimal sediment pulled in alongside them.

The machine itself is lighter than it looks. Bright yellow buoyancy modules dramatically cut its effective weight underwater, spreading that weight evenly across wide tracks so the vehicle glides across the seabed instead of sinking into it. The result is ripples a few centimeters deep rather than trenches. Microbes, the bulk of the seafloor's biomass, live in the top layers of sediment and need that surface intact to recover.



What sediment does enter, passes through an onboard hopper using differential flow and countercurrent washing to 95 to 98 percent of it before the nodules reach the riser.. A diffuser at the back of the vehicle slows that discharge and directs it downward, so the sediment hugs the seafloor and settles within meters rather than drifting upward into the water column.

The small fraction of mud and nodule fines that does travel up the riser gets run through hydrocyclones – centrifuge-like separators that spin out abraded nodule fragments before the remaining water is released. That release happens at 2,000 meters, a depth set with pelagic scientists, including researchers from the University of Hawaii, to sit below 95 percent of marine life, far from where most fisheries feed and breed.

The vessel's own movement helps disperse the outflow, diluting it to background levels within a few hundred meters and keeping measurable effects confined to a small volume of water near the outlet — a deliberate departure from 1970s designs that simply discharged at the surface.

Built on test-mining data, the next-generation Hopper 2.0 pushes that approach further still, increasing both capacity and separation time while folding the hopper into the collector's frame itself — stronger, lighter, and smaller in footprint than the system it replaces.

Learn more here: <https://metals.co/innovation-at-depth/>

## SPOTLIGHT

### *How Odyssey Finds Nodules Without Ever Touching the Seafloor*

Mapping the deep seafloor for minerals requires different techniques depending on the environment and the type of resource being explored. Rather than beginning with physical sampling, Odyssey starts by analyzing existing data to identify where polymetallic nodules are most likely to occur.

Odyssey uses its Global Prospectivity research framework to integrate multivariate geological modeling with geopolitical analysis to identify high-potential marine mineral exploration opportunities worldwide. For polymetallic nodules, that framework incorporates a proprietary analytical tool called Backscatter Angle Range Map Cluster Analysis for Nodules (BAMCAN).

BAMCAN combines multibeam backscatter data with environmental and geological information to identify seafloor geologic domains and predict where polymetallic nodules are most likely to occur. A key advantage of BAMCAN is that it can generate meaningful insights without requiring new offshore survey campaigns.

A lot of multibeam sonar data already exists, collected over decades by different ships for different purposes and sitting largely unused in archives. In one case study, Odyssey applied BAMCAN to survey data gathered across the South Pacific between 2005 and 2023, spanning multiple vessels and systems, and pulled it into a single, consistent picture of nodule prospectivity — no new ship time required.

Results are validated with available seafloor photos, physical samples, and prior survey records. As new data comes in, that comparison runs again. The model gets more reliable over time.

The result is a map of where nodules are likely to occur, plus a secondary read on seafloor habitat. Since nodule fields also represent unique deep-ocean habitats, BAMCAN provides an early understanding of seafloor conditions that can support scientific research, environmental baseline studies, and future exploration planning. Identifying likely nodule distribution helps regulators, scientists, and resource managers better understand these environments before decisions about exploration or development are made. Knowing where nodules occur helps identify areas for further exploration while giving regulators and scientists a better understanding of seafloor conditions before anyone sets sail for fieldwork.

The same principle has guided exploration work in the Cook Islands and elsewhere: better information leads to better decisions. Using existing multibeam data, as well as existing public records of scientific seafloor samples and photographs, provides advanced intelligence to increase confidence in exploration success while providing an early foundation for comprehensive environmental and mineral evaluation.

Learn more from Odyssey Marine Exploration here:

<https://www.odysseymarine.com/post/odyssey-mineral-prospectivity-modelling>

## SPOTLIGHT

### *Impossible Metal's Eureka II and Autonomous Collection*

In May 2024, American ocean-technology company Impossible Metals ran the first deep-water test of an autonomous vehicle purpose-built to selectively collect seabed minerals, sending its Eureka II autonomous underwater vehicle (AUV) to a depth of roughly one mile off the Florida coast. The company had already demonstrated autonomous nodule collection in shallower water late the previous year; this test showed the vehicle could navigate and operate untethered at commercially relevant depths.

Eureka is one of several distinct engineering approaches now in development across the industry. Rather than a single collector vehicle tethered to a surface ship, Eureka uses a fleet of individual AUVs, each with computer vision and onboard AI, to identify and lift polymetallic nodules one at a time while hovering just above the seafloor.

Impossible Metals' approach centers on two design choices specific to this system. On operations, the fleet-based model is designed to reduce reliance on a single large surface vessel and to keep each AUV working independently, so that one unit's downtime does not halt the wider collection effort and fewer costly support ships are required. On environmental performance, the company says each AUV's cameras and AI are built to identify visible marine life on a nodule and leave it in place, and that hovering, rather than remaining in continuous contact with the seabed, is intended to limit sediment disturbance during collection.

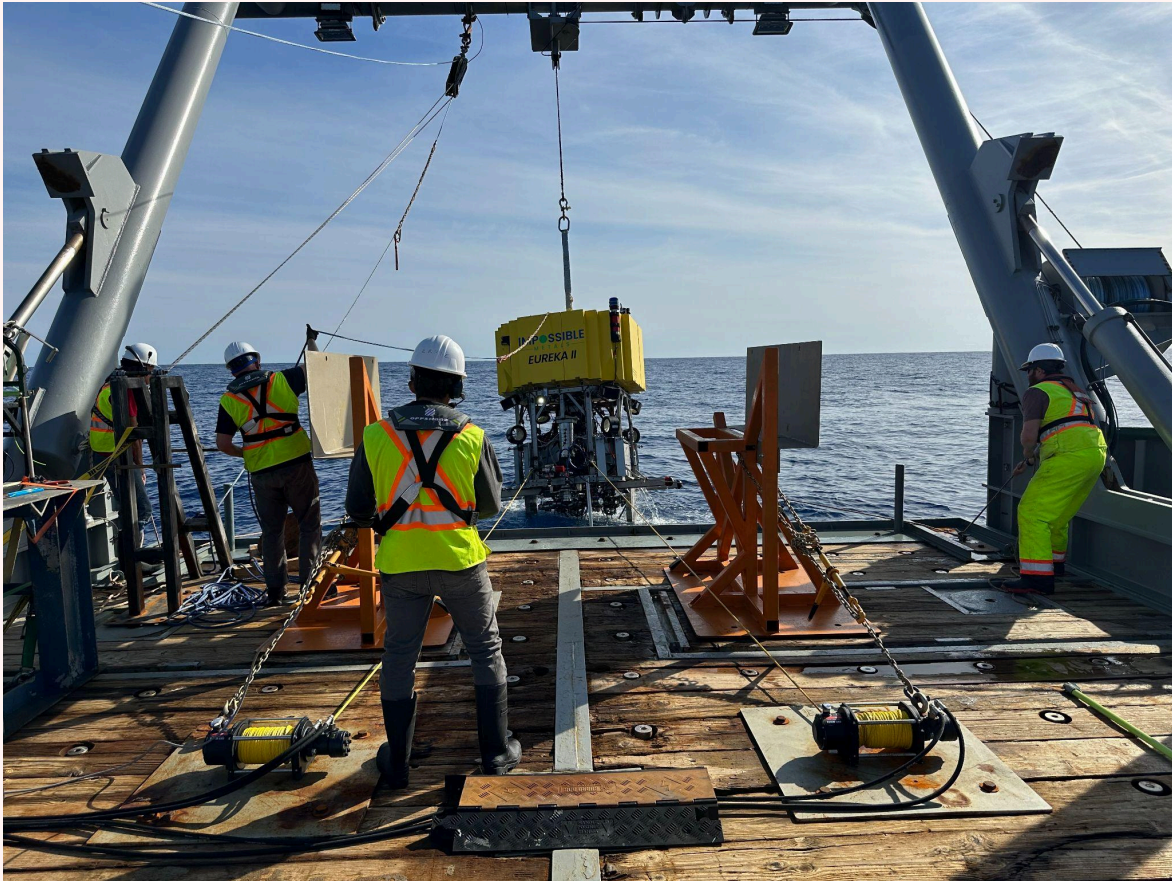


*image source:*

Steve Curnutte, Impossible Metals' Executive Chairman, described the Florida dive as proof of Eureka II's autonomous navigation in deep water, building on the earlier collection trial. AUV specialist Justin Manley, who advises the company, pointed to the pace of the work—two generations of functional AUVs built in two years—as a measure of how quickly the engineering has progressed.

Impossible Metals is advancing collection technology toward commercial readiness, testing different answers to the same question: How do we recover critical minerals for a modern economy at scale, while limiting its impact?

# Demand is Outrunning Supply

## Why Terrestrial Supply Can't Keep Pace

Cobalt goes into the cathodes of high-performance batteries and into the superalloys that keep jet turbine blades intact at extreme temperatures. Nickel strengthens military plating and feeds the same battery supply chain every major automaker is racing to secure. Rare earth elements sit inside the permanent magnets of missile guidance systems, fighter aircraft, wind turbines, and electric motors, all applications with no near-term substitute, and ones where China controls roughly 90 percent of global processing capacity.<sup>13</sup>

These are foundational materials running through defense, energy, and transportation at the same time, and the infrastructure built to mine and process them on land isn't expanding quickly enough to keep up. The IEA projects mineral demand for renewable energy technologies alone will double by 2030 and nearly triple by 2050<sup>14</sup>. The World Bank puts long-run demand growth at 500 percent by mid-century<sup>15</sup>. Artificial intelligence infrastructure is now its own demand driver: data centers alone are projected to require 330,000 to 420,000 tons of copper by 2030, and S&P Global forecasts a 10-million-ton copper shortfall by 2040<sup>16</sup>.

## Three Sectors With Converging Demand

- Electric Vehicles (EVs)
  - Battery demand more than quadrupled between 2018 and 2023 and is projected to grow tenfold or more by 2050<sup>17</sup>
  - Every vehicle requires nickel, cobalt, manganese, copper, and rare earth elements in the battery pack
  - Gigafactories under construction or in final investment decision across the U.S., Europe, South Korea, and Japan represent a demand commitment that runs for decades

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<sup>13</sup> <https://www.wilsoncenter.org/publication/polymetallic-nodules-and-critical-minerals-supply-chain-north-american-approach>

<sup>14</sup> <https://iea.blob.core.windows.net/assets/ee01701d-1d5c-4ba8-9df6-abeac9de99a/GlobalCriticalMineralsOutlook2024.pdf>

<sup>15</sup> <https://www.worldbank.org/en/news/press-release/2020/05/11/mineral-production-to-soar-as-demand-for-clean-energy-increases>

<sup>16</sup> <https://press.spglobal.com/2026-01-08-Substantial-Shortfall-in-Copper-Supply-Widens-as-the-Race-for-AI-and-Growing-Defense-Spending-Add-to-Accelerating-Demand.-New-S-P-Global-Study-Finds>

<sup>17</sup> <https://www.iea.org/reports/global-ev-outlook-2024/outlook-for-battery-and-energy-demand>

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- Grid-Scale Energy Storage
  - The fastest-growing demand segment, expanding at rates that already exceed light-duty vehicle growth in some scenarios <sup>18</sup>
  - Large-format battery systems require the same minerals as EV batteries — nickel, cobalt, manganese, copper, and rare earth elements — compounding the transportation demand signal
  - As renewable energy penetration increases, storage deployment accelerates with it
- Defense & Advanced Manufacturing
  - Cobalt is used in fighter jet components and armor-penetrating munitions; nickel goes into military-grade plating and high-performance steel alloys <sup>19</sup>
  - Rare earth elements are embedded in virtually every U.S. defense platform using permanent magnet motors or precision guidance systems
  - Defense requirements cannot shift to substitutes when supply tightens — making supply disruption a readiness issue

Benchmark Mineral Intelligence projects a cobalt supply shortfall of 45,800 tons against demand by 2035, with nickel facing a gap of 800,000 tons over the same stretch.<sup>20</sup> Those shortfalls land just as battery and defense manufacturing are both scaling up.

Seabed minerals are positioned to fill these gaps. It's one of the few supply options that can come online on the same timeline as the demand curve, sit outside adversary-controlled processing infrastructure, and exist in quantities large enough to actually move the shortfall numbers rather than round to zero against them. For an American industrial base trying to secure battery supply, grid storage capacity, and defense readiness simultaneously, that combination is worth building toward.

## Different Resources, Different Roles

Deep-sea mining is often portrayed as a single activity, but the seafloor tells a much more nuanced story. Beneath the ocean lie at least five major mineral resource types—each created by different geological processes, found in different marine environments, and requiring distinct technologies, regulatory pathways, and development timelines. Treating them as one category obscures more than it explains.

**Nodules.** Unattached to the seafloor across the abyssal plains of the Clarion-Clipperton Zone (CCZ) at depths of 13,000 to 21,000 feet [4,000 to 5,500 meters], nodules sit on the sediment rather than bonded to rock, which is why they can be lifted with water jets or robotic arms

<sup>18</sup> <https://www.iea.org/reports/global-ev-outlook-2024/outlook-for-battery-and-energy-demand>

<sup>19</sup> <https://www.wilsoncenter.org/publication/polymetallic-nodules-and-critical-minerals-supply-chain-north-american-approach>

<sup>20</sup> <https://source.benchmarkminerals.com/article/battery-cathode-material-deficits-continue-to-be-expected-by-the-end-of-decade>

instead of cut free. They're dominated by nickel, copper, cobalt, manganese, and rare earth elements, the same metals that go into stainless steel and superalloys, and increasingly into the nickel-manganese-cobalt cathodes used in EV batteries.<sup>21</sup> Estimates put the CCZ's nickel content at roughly 270 million tons and cobalt at roughly 40 million tons, both larger than current land-based reserves, alongside an estimated 6 billion tons of manganese<sup>22</sup>. Nodules are the long-term supply base: the deposit closest to commercial reality and large enough to matter for decades of battery and alloy demand.

**Seafloor massive sulfides (SMS).** Formed at hydrothermal vents where mineral-rich water escapes the crust, SMS deposits concentrate copper, zinc, gold, and silver, base and precious metals with established markets, alongside a long list of strategic byproducts: gallium, germanium, tellurium, indium, and other elements used in semiconductors and electronics<sup>23</sup>. Because the ore sits in dense vent structures rather than spread across a plain, SMS can deliver higher grades per ton, which is what makes it attractive as an early-stage, higher-margin resource even with smaller total volumes.

**Crusts.** Growing on seamount flanks at just 1 to 5 millimeters per million years, cobalt-rich crusts hold cobalt, manganese, and nickel for batteries and alloys, plus platinum and rare earths used in catalysts and magnets<sup>24</sup>. They're fused directly to hard rock, which makes them more difficult to separate and less suited to bulk supply, better suited to specific high-value elements than to large-scale tonnage.

**Sands.** Concentrated by waves and currents in coastal shallows, heavy mineral sands carry titanium and zirconium used in pigments, alloys, and aerospace components, along with platinum, gold, and rare earths<sup>25</sup>. They're already the most commercially mature seabed resource, close enough to shore that some U.S. states already mine them through beach replenishment efforts.

**Muds.** Discovered in Pacific sediment by University of Tokyo researchers in 2011, REE-rich muds concentrate heavy rare earths like yttrium, terbium, and dysprosium, elements used in permanent magnets, lasers, and the phosphors in display screens, and are among the most exposed to Chinese supply concentration<sup>26</sup>. The original survey put the resource's scale at roughly 1,000 times known land-based reserves, and researchers have suggested it could meet global demand for some of these elements for centuries, though detailed extraction modeling has so far only been worked out for a 30-to-60-year window<sup>27</sup>. Japan has since invested in pumping technology and confirmed successful test retrieval from the seafloor.

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<sup>21</sup> [https://www.rand.org/pubs/research\\_reports/RRA3560-1.html](https://www.rand.org/pubs/research_reports/RRA3560-1.html)

<sup>22</sup> <https://www.wilsoncenter.org/publication/polymetallic-nodules-and-critical-minerals-supply-chain-north-american-approach>

<sup>23</sup> <https://pubs.usgs.gov/fs/2025/3017/fs20253017.pdf>

<sup>24</sup> <https://www.congress.gov/crs-product/R47324>

<sup>25</sup> <https://pubs.usgs.gov/fs/2025/3017/fs20253017.pdf>

<sup>26</sup> <https://iea.blob.core.windows.net/assets/ee01701d-1d5c-4ba8-9df6-abeeac9de99a/GlobalCriticalMineralsOutlook2024.pdf>

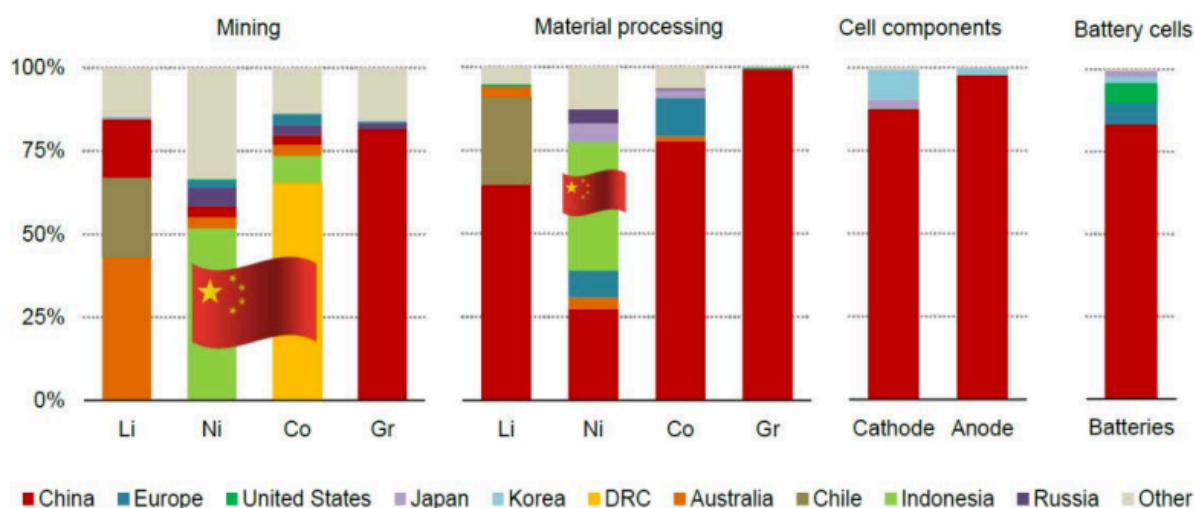
<sup>27</sup> [https://www.researchgate.net/publication/253929395\\_Deep-sea\\_mud\\_in\\_the\\_Pacific\\_Ocean\\_as\\_a\\_potential\\_resource\\_for\\_rare-earth\\_elements](https://www.researchgate.net/publication/253929395_Deep-sea_mud_in_the_Pacific_Ocean_as_a_potential_resource_for_rare-earth_elements)

Taken together, these five types fulfill varied and important purposes rather than competing for the same role: sands and SMS for near-term, high-grade recovery of established industrial metals; nodules for the long-term battery and alloy supply base; crusts for narrow high-value niches; and muds as the deepest-dated reserve still being proven out.

## In the Driver's Seat: How China dominated critical mineral mining and processing and how it has used that position as a policy instrument

China processes roughly 90 percent of the world's rare earth elements, 65 percent of global nickel, 60 percent of global cobalt, and 74 percent of global lithium.<sup>28,29</sup> The U.S. now relies solely on imports for 16 critical minerals, and China is a top producer of at least half of those materials.<sup>30</sup> It is a national imperative for U.S. policymakers to loosen China's grip.

Critical minerals are mined all over the world, but most of the supply ends up passing through China. For a broad range of key metals and minerals, China is either the largest miner, the dominant processor, or both. This is true for rare earths, lithium, cobalt, graphite, nickel, and many other metals and minerals that are essential to defense, energy, and high-tech applications.<sup>31</sup>



SOURCE: Adapted from International Energy Agency (IEA), 2024, p. 30 (CC BY 4.0).

NOTE: Chinese flags indicate large shares of Chinese ownership of foreign operations. Li = lithium; Ni = nickel; Co = cobalt; Gr = graphite; DRC = Democratic Republic of the Congo.

Image source: [https://www.rand.org/content/dam/rand/pubs/research\\_reports/RRA3500/RRA3560-1/RAND\\_RRA3560-1.pdf](https://www.rand.org/content/dam/rand/pubs/research_reports/RRA3500/RRA3560-1/RAND_RRA3560-1.pdf)

<sup>28</sup> <https://www.wilsoncenter.org/publication/polymetallic-nodules-and-critical-minerals-supply-chain-north-american-approach>

<sup>29</sup> <https://www.iea.org/reports/global-critical-minerals-outlook-2024>

<sup>30</sup> <https://nam.org/federal-data-show-growing-u-s-reliance-on-imported-critical-minerals-35728/?stream=series-input-stories>

<sup>31</sup> [https://www.realcleardefense.com/articles/2026/04/03/how\\_china\\_dominates\\_the\\_worlds\\_critical\\_minerals\\_production\\_1174451.html](https://www.realcleardefense.com/articles/2026/04/03/how_china_dominates_the_worlds_critical_minerals_production_1174451.html)

China's position in critical mineral processing reflects a sustained, deliberate industrial strategy that extends beyond commercial returns.<sup>32</sup> The result of this strategy is a processing infrastructure that the rest of the world depends on and that China has demonstrated a clear willingness to use as a policy instrument.

In 2010, following a maritime dispute with Japan, Chinese state-owned enterprises restricted rare earth exports to Japanese customers. Prices rose to six times their average trading value and remained elevated for four years<sup>33</sup>. In July 2023, China imposed export controls on gallium, germanium, and certain graphite products, triggering a surge in prices.<sup>34</sup> In August 2024, antimony exports were restricted.<sup>35</sup> In October 2024, China blocked the sale of critical battery components to a U.S. drone manufacturer supplying Ukraine<sup>36</sup>. In December 2024, following U.S. semiconductor export controls, China fully banned exports of gallium, germanium, antimony, and superhard materials to the United States<sup>37</sup>. Each episode followed the same pattern: a diplomatic or trade tension, a targeted export restriction on materials the U.S. and its allies cannot easily source elsewhere, and an extended period of elevated prices and supply uncertainty.

For rare earth elements, the materials most critical to defense systems, precision guidance, and electric motor magnets, the concentration is more acute still. China processes roughly 90 percent of global rare earth output. They carry the highest supply risk of any mineral category, and the gap between where they are processed and where they need to go is almost entirely controlled by a single country. The United States has made efforts to rebuild domestic rare earth processing capacity, but those efforts remain in early stages relative to the scale of Chinese infrastructure that has accumulated over decades.

Supply chains this concentrated in a single country create leverage that extends beyond economics. They give China the ability to affect U.S. manufacturing output, defense production timelines, and technology sector competitiveness. Western companies have learned this the hard way through each successive round of restrictions.

Allied nation seabed mineral development addresses this directly. The fields contain cobalt, nickel, and manganese in quantities sufficient to supply meaningful portions of U.S. and allied demand, extracted under American or allied regulatory oversight, processed in North American facilities, and delivered through supply chains that don't pass through Chinese-controlled infrastructure. Combined with expanded terrestrial production, allied partnerships, and domestic processing investment, it creates a more resilient supply base for the United States and our allies.

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<sup>32</sup> <https://www.rand.org/pubs/articles/2026/could-deep-sea-mining-break-chinas-grip-on-critical.html>

<sup>33</sup> <https://cepr.org/voxeu/columns/revisiting-china-japan-rare-earths-dispute-2010>

<sup>34</sup> [https://www.usitc.gov/publications/332/executive\\_briefings/ebot\\_germanium\\_and\\_gallium.pdf](https://www.usitc.gov/publications/332/executive_briefings/ebot_germanium_and_gallium.pdf)

<sup>35</sup> <https://www.csis.org/analysis/chinas-antimony-export-restrictions-impact-us-national-security>

<sup>36</sup> <https://www.yahoo.com/news/china-imposes-sanctions-us-drone-080101295.html>

<sup>37</sup> <https://www.reuters.com/markets/commodities/china-bans-exports-gallium-germanium-antimony-us-2024-12-03/>

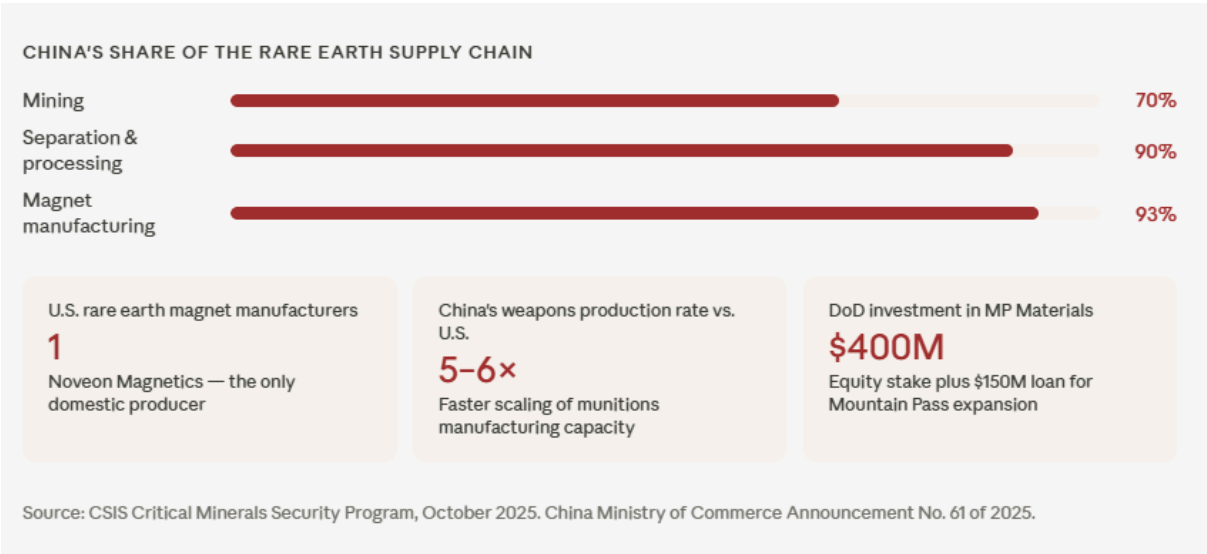
BREAKOUT

What China Controls Can Ground the U.S. Military

Rare earth permanent magnets sit inside nearly every weapons system the U.S. military fields, from F-35 actuators and avionics, Virginia-class submarine drive motors, Tomahawk guidance systems, Predator UAVs, and JDAM fin actuation. China produces roughly 90 percent of the world's rare earth processing output. In October 2025, it decided to use that position.<sup>38</sup>

RARE EARTH PERMANENT MAGNETS ARE EMBEDDED IN THE BACKBONE OF U.S. MILITARY CAPABILITY.

| F-35 fighter jet                            | Virginia & Columbia-class submarines    | Tomahawk missiles               | Radar & UAV systems                            | JDAM smart bombs                     |
|---------------------------------------------|-----------------------------------------|---------------------------------|------------------------------------------------|--------------------------------------|
| Magnets in actuators, sensors, and avionics | Electric drive motors and sonar systems | Guidance and propulsion systems | Predator UAVs, radar arrays, targeting systems | Precision guidance and fin actuation |



In October 2025, China's Ministry of Commerce Announcement No. 61 introduced the strictest rare earth and permanent magnet export controls ever implemented, borrowing the foreign direct product rule that the U.S. pioneered for semiconductor restrictions and turning it around.<sup>39</sup> Under the new framework, any magnet containing even trace amounts of Chinese-origin rare earth material requires Chinese government approval to export.

<sup>38</sup> <https://www.csis.org/analysis/chinas-new-rare-earth-and-magnet-restrictions-threaten-us-defense-supply-chains>

<sup>39</sup> <https://cset.georgetown.edu/publication/mofcom-notice-2025-61/>

Given China's dominance in processing, that threshold impacts nearly every magnet made anywhere in the world. Companies with affiliations to foreign militaries, including U.S. defense contractors, are largely denied licenses. Requests to use rare earths for military purposes are automatically rejected.

The U.S. response has started. The Department of War took a \$400 million equity stake in MP Materials in July 2025, committed to a 10-year price floor for neodymium-praseodymium output, and extended a \$150 million loan to add heavy rare earth separation at Mountain Pass.<sup>40,41</sup> Noveon Magnetics, currently the only U.S. manufacturer of rare earth magnets, received over \$35 million to expand domestic production.<sup>42</sup>

By developing its own resource stream — seabed and terrestrial — alongside the processing infrastructure to finish what it extracts, the United States can become more mineral independent to help the U.S. defense build a more secure and durable industrial base.

## BREAKOUT

### *The Strategic Seafloor: China's Push for Deep-Sea Dominance*

China holds five ISA exploration contracts in international waters — more than any other single country — covering nodule, crust, and sulfide fields across the Pacific and Indian Oceans. But the mineral position is only part of the picture.

Those five contracts cover roughly 238,000 square kilometers, an area about the size of the United Kingdom, and China is the only country holding contracts across all three seabed mineral types. Its institutional position is at least as significant. Beijing has served almost continuously on the 36-member ISA Council since 2001 and has been the Authority's largest financial contributor since 2021. It funds voluntary trust programs supporting developing-country participation, has nationals embedded across ISA technical and financial committees, and hosts the ISA-China Joint Training and Research Centre in Qingdao, the first permanent joint ISA research facility established with any member state. It has used that position to oppose the creation of an independent inspection body for environmental compliance enforcement.

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<sup>40</sup> <https://investors.mpmaterials.com/investor-news/news-details/2025/MP-Materials-Announces-Transformational-Public-Private-Partnership-with-the-Department-of-Defense-to-Accelerate-U-S--Rare-Earth-Magnet-Independence/default.aspx>

<sup>41</sup> <https://mpmaterials.com/news/mp-materials-announces-transformational-public-private-partnership-with-the-department-of-defense-to-accelerate-u-s-rare-earth-magnet-independence/>:

<sup>42</sup> <https://www.dodmantech.mil/News/News-Display/Article/3700059/dod-looks-to-establish-mine-to-magnet-supply-chain-for-rare-earth-materials/>

In March 2026, Reuters reported that dozens of Chinese research vessels had been systematically mapping the seafloor across the Pacific, Indian, and Arctic Oceans, collecting data on underwater terrain, water temperature, salinity, and current patterns in waters near Guam, Hawaii, Taiwan, and Australian submarine bases. Rear Admiral Mike Brookes, commander of the U.S. Office of Naval Intelligence, testified to a Congressional commission that the effort provides data that "enables submarine navigation, concealment, and positioning of seabed sensors or weapons."

The mineral and military programs are part of the same program. Beijing's civil-military fusion policy – a national strategy formally adopted to integrate civilian economic development with military modernization – treats scientific research and defense capability as a unified effort. The vessels conducting nodule surveys are generating the same bathymetric data that informs submarine operations. One Ocean University researcher said publicly that his ocean monitoring work would help "transform the most advanced scientific and technological achievements into new types of combat capabilities for our military at sea."<sup>43</sup>

The fleet behind that effort has grown from 19 research vessels in 2012 to more than 64 today, completing 93 ocean-going expeditions across every major ocean basin during China's most recent Five-Year Plan. In 2024, its Pioneer II mining vehicle operated at 4,102.8 meters and retrieved over 200 kilograms of nodules and crusts, and in 2025 the ISA cleared China Minmetals to conduct test mining in its contract area. Beijing is pairing that capability with Pacific dealmaking: a five-year seabed minerals cooperation agreement with the Cook Islands in February 2025, and discussions opened with Kiribati immediately after a Western operator terminated its arrangement covering nearly 75,000 square kilometers of seabed.

Traditional naval hydrographic surveys focus on safe transit corridors for surface and subsurface vessels. Deep-sea mining surveys cover previously unmapped areas of the seabed – including regions adjacent to strategic submarine operating zones – in fine resolution suitable for sonar masking and acoustic signature analysis. The difference between knowing where a trench lies and knowing how sound propagates through it is material to submarine concealment.

That dual use is the part American policy has historically been slow to absorb. Traditionally, Washington debated seabed mining mostly as a minerals problem – cobalt tonnage, refining capacity, EV supply chains – while China has treated its survey fleet as a way to chart the seafloor near contested waters years before any conflict would make that terrain matter.

A Mongabay and CNN investigation tracking eight Chinese research vessels over five years found they spent roughly 6 percent of their total open-water time in or near ISA-designated exploration areas.<sup>44</sup> A July 2025 New York Times investigation using

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<sup>43</sup> <https://indiandefencereview.com/chinese-deploys-42-ships-to-prepare-submarine-war-against-us-navy/>

<sup>44</sup> <https://news.mongabay.com/2026/06/how-we-tracked-chinas-deep-sea-mining-fleet/>

Starboard Maritime tracking data documented systematic grid-pattern bathymetric surveys off Taiwan's east coast and approximately 250 miles east and west of Guam. The Xiang Yang Hong 6 surveyed waters west of Guam that contain no ISA contract areas and no known mineral deposits, but a dense network of undersea fiber-optic cable. The contract areas themselves track U.S. strategic geography: Beijing Pioneer's sits under 400 miles from the Northern Mariana Islands, and China Minmetals' areas are roughly 600 miles from Hawaii.

America's answer will be to build the best technology and collection operations, support responsible rules, and stand up for our values on the world stage.

## Processing is Power

Harvesting nodules off the seafloor gets the most attention, but it is not the only step with significant strategic value. Raw nodules require two industrial stages — smelting and processing — before they become usable nickel, cobalt, and manganese.

Without domestic processing capacity, the U.S. extracts the resource and then ships it offshore to finish — undercutting the cost case for seabed mining and the onshoring capability it was supposed to build. That finishing step runs almost entirely through Chinese-controlled infrastructure,<sup>45</sup> so the supply chain dependency the program was meant to solve stays intact.

There are no ferronickel smelting facilities anywhere in North America at present. Ferronickel is important because it serves as the primary and most cost-effective raw material for producing stainless steel. It is an alloy composed of roughly 20% to 40% nickel and 60% to 80% iron.<sup>46</sup> Global smelting capacity sits in countries outside U.S. trade agreements, built largely with Chinese capital and designed to keep processing value within Chinese-controlled systems regardless of where the ore originates.

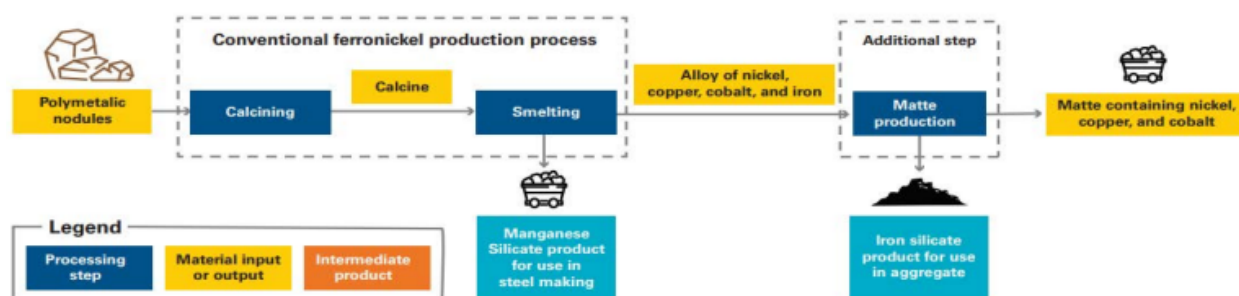


Table source:: [https://www.rand.org/content/dam/rand/pubs/research\\_reports/RRA3500/RRA3560-1/RAND\\_RRA3560-1.pdf](https://www.rand.org/content/dam/rand/pubs/research_reports/RRA3500/RRA3560-1/RAND_RRA3560-1.pdf)

In a pilot campaign, The Metals Company and Japan's PAMCO (Pacific Metals Co.) ran seafloor polymetallic nodules through an existing commercial ferronickel line, producing 2,000 tons of nickel-copper-cobalt product and a saleable manganese silicate with effectively no solid

<sup>45</sup> <https://www.wilsoncenter.org/publication/polymetallic-nodules-and-critical-minerals-supply-chain-north-american-approach>

<sup>46</sup> <https://ui.adsabs.harvard.edu/abs/2016cm16.book..143L/abstract>

processing waste.<sup>47</sup> It showed that nodules can move through established smelting and refining infrastructure, which is the step skeptics most often assume is unproven.

Smelting and refining are mature industries, and North American engineering firms already have the expertise — the continent runs nickel, copper, and zinc refineries today,<sup>48</sup> just not ones built to handle nodule-derived material. That's the piece that has to be built new. But a facility purpose-built for nodules wouldn't be a one-off asset tied to a single source: it could run ore from domestic mines, offshore operations, or allied-nation supply just as well, which means the investment pays off across the entire domestic resource base, not one narrow feedstock.<sup>49</sup>

**Learn More:** <https://www.wilsoncenter.org/publication/polymetallic-nodules-and-critical-minerals-supply-chain-north-american-approach>

Building that capacity domestically carries real operational advantages. Co-locating smelting and processing on the same site cuts out transport costs and brings supply chains closer to where they are needed. .

But the bigger issue is what's missing from the critical minerals argument overall: without domestic processing, neither offshore nor terrestrial mineral development can deliver on the strategic promise behind them. Closing that gap is what actually turns raw ore, wherever it's mined, into finished metal produced on American soil and out of reach of the next Chinese export restriction.

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<sup>47</sup> <https://investors.metals.co/news-releases/news-release-details/world-first-tmc-and-pamco-achieve-new-nodule-processing>

<sup>48</sup> [https://www.rand.org/content/dam/rand/pubs/research\\_reports/RRA3500/RRA3560-1/RAND\\_RRA3560-1.pdf](https://www.rand.org/content/dam/rand/pubs/research_reports/RRA3500/RRA3560-1/RAND_RRA3560-1.pdf)

<sup>49</sup> <https://www.wilsoncenter.org/publication/polymetallic-nodules-and-critical-minerals-supply-chain-north-american-approach>

## BREAKOUT

### *Processing a Novel Feedstock with Established Technology*

A polymetallic nodule is, chemically, four metals in one rock – nickel, copper, cobalt, manganese, and rare earth elements bound together in roughly the same proportions found in land-based nickel laterite ore. Rather than inventing new metallurgical processes, the leading approach to nodule processing borrows directly from the conventional ferronickel production line already running in laterite-processing countries like Indonesia and the Philippines.

First, pyrometallurgy: nodules are calcined in a kiln to drive off oxygen, then smelted in an electric furnace, which splits the material into a manganese silicate byproduct – sellable to steelmakers – and a molten nickel-copper-cobalt-iron alloy. Reacting that alloy with sulfur in a converter strips out the iron as an inert silicate (usable as aggregate) and leaves a nickel-copper-cobalt matte, the same intermediate product nickel smelters have produced commercially for decades.

Second, hydrometallurgy: that matte goes to a nickel refinery, where acid leaching dissolves the nickel and cobalt while leaving copper behind for separate recovery. Each metal is then purified into a sellable form – copper cathode, nickel and cobalt metal or sulfate salts for battery cathode producers.

Ion exchange leaching has separately proven itself as an REE extraction method in a different seabed-adjacent context: ionic adsorption clay deposits, where research shows roughly 90 percent of contained rare earths sit in a form that ion exchange can access directly, without smelting or high-pressure processing first.<sup>50</sup>

None of the three routes requires inventing new chemistry. What's novel is the feedstock, and that matters for how fast a nodule supply chain could actually scale.

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<sup>50</sup> <https://www.sciencedirect.com/science/article/abs/pii/S0263876224003538>

## America Already Has the Tools

The companies, vessels, and workforce that built the offshore energy industry are the same ones positioned to develop American seabed minerals. Marine engineers, ROV pilots, subsea systems operators, geophysical surveyors, and vessel crews are working today along the Gulf of America coast and in offshore operations around the world, applying skills that translate directly to ocean mineral development.

Technologies and processes like dynamic positioning, riser pipelines, ROVs, hydraulic lift systems, subsea sensors, and geophysical survey platforms have decades of commercial precedent in offshore energy.



image source:

<https://www.bbc.com/future/article/20230310-what-does-the-high-seas-treaty-mean-for-deep-sea-mining>

**The collection vehicles that work the abyssal plain, whether tracked collectors or free-swimming autonomous robots, are purpose-built for mineral collection, and they are where American engineering is furthest ahead. The systems that support them from the surface, the vessel, the positioning system, the riser where one is used, and the monitoring equipment, are drawn from technology the industry already operates.**

The geophysical capability is equally established. Multibeam sonar, sub-bottom profiling, acoustic seafloor imaging, the tools that characterize nodule fields, define environmental baselines, and underpin permit applications, are standard services that U.S. survey companies already provide globally. The data interpretation expertise sits in the same firms and university research programs that have supported offshore energy for generations.

The offshore sector also holds a safety and environmental management culture built through decades of operating in demanding conditions under rigorous regulatory oversight. The companies, personnel, and management systems shaped by that experience carry those standards into every offshore environment they work in. American-led seabed mineral operations inherit that culture, and with it, a credibility on environmental performance that operators from less regulated environments cannot match.

The ports, fabrication yards, and logistics networks that support offshore energy extend naturally to mineral development as well. Gulf Coast facilities with heavy lift and bulk cargo capability, supply chains that move specialized equipment to remote offshore locations, and

maintenance and engineering services that keep complex subsea systems running, all of it is already sized for the demands a commercial nodule operation would generate.

## BREAKOUT

### *Building the Future*

America's offshore capability is the foundation for our future leadership. Ocean minerals are a new industry, and its leadership is contested. The rules for how these resources are developed, the standards operators are held to, and the practices that become customary are being decided now.

America has the opportunity to lead. We can set the rules in accord with our values and build a massive new export industry. Every nation with critical minerals demand and access to seabed resources will need collection systems, monitoring packages, and survey capability to develop them responsibly, and American companies can supply that technology alongside the minerals themselves.

Innovation is our competitive advantage. Autonomy, machine vision, edge computing, energy-dense subsea power, and selective handling are where America is ahead of China and pulling away.

The offshore industry built the foundation. Now we build the future on it.

## Ports, Processing, & American Jobs

Seabed mineral development generates employment across a supply chain that runs from the seafloor to the factory floor. The offshore component, including vessel operations, subsea systems, geophysical survey work, and environmental monitoring, draws directly from the existing maritime workforce. The port and logistics infrastructure that handles nodules creates sustained throughput for terminal operators, stevedores, and the broader port services economy. And the processing facilities that convert raw nodules into battery-grade and defense-grade metals represent the kind of anchor industrial investment, smelters, processors, fabrication supply chains, that creates durable, place-based employment in the communities that host them.

Each stage of that chain has a multiplier effect on the broader economy. Processing facilities in particular generate supplier ecosystems in maintenance, chemicals, engineering services, and equipment manufacturing that extend far beyond the facility fence line. Research institutions and universities benefit from the sustained scientific and engineering demand that commercial development creates, supporting graduate programs, national laboratory partnerships, and technology contracts that strengthen American technical capacity across ocean science, subsea engineering, and advanced materials.

The downstream connection ties the employment picture together. Battery precursor producers are building manufacturing capacity across the United States and Canada to supply the EV and energy storage industries. A domestic processing industry producing nickel, cobalt, and manganese at battery grade feeds directly into that supply chain – replacing imported intermediates with American-produced inputs and anchoring the critical minerals value chain on home soil.

Taken together, the employment generated by seabed mineral development is broad, durable, and distributed, spanning coastal port communities, inland manufacturing regions, and research centers alike. It is not a single project's worth of construction jobs. It is the foundation of a new American industrial sector.

## Funding America's Future: The Industrial and Economic Potential of Seabed Minerals

The industrial argument for American seabed mineral development starts with a straightforward observation: As of 2024, the United States was 100 percent net-import reliant for 12 critical minerals, and 50 percent or greater net-import reliant for a further 29 critical minerals.<sup>51</sup> For each of those materials, the country is paying a foreign producer, a foreign processor, or both, and in many cases, routing that payment through supply chains where Chinese state industrial policy shaped the price, the availability, and the terms.

**100%**

The U.S. is 100% net import  
reliant for 12 critical minerals

**50%**

The U.S. is 50% or greater net-import  
reliant on an additional 29 critical minerals

Seabed mineral development can change that equation by creating domestic and allied-nation supply of materials the American economy currently cannot source at home, and it builds the processing infrastructure that converts raw material into finished industrial inputs: the battery-grade nickel sulfate, the refined cobalt, the manganese silicate that American manufacturers need.

Minerals-based industries contributed over \$4 trillion to the U.S. economy in 2024.<sup>52</sup> Inclusion on the Critical Minerals List carries real policy consequences. Listed minerals become eligible for federal funding, streamlined permitting processes, and import fee advantages that unlisted minerals do not receive.<sup>53</sup> Dr. Gracelin Baskaran, director of the Critical Minerals Security Program at the Center for Strategic and International Studies (CSIS), described the list as: "a signal to the market about federal policy priorities."<sup>54</sup>

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<sup>51</sup> <https://www.usgs.gov/news/national-news-release/usgs-value-us-mineral-production-edged-2024>

<sup>52</sup> <https://www.usgs.gov/news/national-news-release/usgs-value-us-mineral-production-edged-2024>

<sup>53</sup> <https://bipartisanpolicy.org/article/building-a-winning-roster-usgss-draft-critical-minerals-list/>

<sup>54</sup> <https://www.linkedin.com/pulse/silver-designated-critical-mineral-us-government-money-metals-sxx8e/>

At the extraction level, production estimates from active commercial projects suggest that a relatively modest number of collection vessels, operating in the CCZ, in allied-nation EEZs, or both, could supply meaningful portions of projected U.S. cobalt and nickel demand by 2040.<sup>55</sup>

The processing layer is where the larger industrial investment concentrates, and where the United States has the most ground to make up. China produces 45 percent of global refined copper, 35 percent of refined nickel, 78 percent of refined cobalt, and 95 percent of refined manganese. There is strong interest and need to process nodules in the United States, thanks to the proximity to the CCZ, access to low-cost and low-emission electricity, deep-water ports, metallurgical expertise, and production tax credit incentives.<sup>56</sup>

### Chinese Share of Global Production

|                |                |                |                   |
|----------------|----------------|----------------|-------------------|
| 45%            | 35%            | 78%            | 95%               |
| refined copper | refined nickel | refined cobalt | refined manganese |

Nodule processing differs from terrestrial ore processing. Nodules are a complex oxide matrix containing multiple metals in varying concentrations, requiring processing routes that are still being optimized at pilot and industrial scale. Pyrometallurgical, hydrometallurgical, and hybrid approaches are all under development, each with different capital requirements, energy intensity, and waste stream profiles.

Federal incentives – including the Section 45X Advanced Manufacturing Production Credit – remain available to offset the capital cost of building domestic processing capacity. But the scale of investment required for commercial-scale refining facilities is substantial, and private capital will require certainty of feedstock supply before committing.

Building domestic processing capacity, smelters and processors capable of converting nodule-derived matte into battery-grade and defense-grade metals, goes beyond minerals infrastructure investment. It is the investment that activates the entire upstream value chain. Without a domestic offtake pathway, seabed mineral extraction delivers raw material to foreign processors, and the U.S. captures none of the manufacturing value.

<sup>55</sup> [https://www.rand.org/content/dam/rand/pubs/research\\_reports/RR4300/RR4350/RR4350-1/RAND\\_RRA3560-1.pdf](https://www.rand.org/content/dam/rand/pubs/research_reports/RR4300/RR4350/RR4350-1/RAND_RRA3560-1.pdf)

<sup>56</sup> [https://www.rand.org/content/dam/rand/pubs/research\\_reports/RR4300/RR4350/RR4350-1/RAND\\_RRA3560-1.pdf](https://www.rand.org/content/dam/rand/pubs/research_reports/RR4300/RR4350/RR4350-1/RAND_RRA3560-1.pdf)

## Responsible Development, American-aligned Standards

The offshore industry understands environmental responsibility. It operates under some of the most rigorous regulatory regimes in the world, with mandatory monitoring, independent oversight, and enforceable permit conditions that have shaped operational culture across decades of deepwater energy development. That same culture, many of the same companies, the same workforce, the same management systems, is what American-aligned seabed mineral development brings to the seafloor.

Ocean mineral resource exploration begins with science. Before any collection activity occurs, operators conduct comprehensive pre-disturbance baseline surveys, autonomous underwater vehicles and hull-mounted multibeam on survey ships to map the seafloor in high resolution, characterizing nodule distribution, sediment composition, benthic biological communities, and oceanographic conditions across the full project area. That baseline is not a regulatory checkbox. It is the foundation that makes adaptive management possible, and that gives regulators, scientists, and the public a verifiable picture of conditions before and after operations.

During collection, real-time monitoring systems on the collector vehicle or AUV and, in riser-based systems, on the riser itself, track sediment plume behavior, water column conditions, and operational parameters continuously. If readings deviate from permitted parameters, operations are required to adjust. These monitoring protocols have been tested during collection trials; their effectiveness at commercial scale will be validated through the adaptive management framework that DSHRMA and BOEM permitting require.

Direct disturbance of the seafloor ecosystem is the most substantive environmental concern associated with nodule collection, and it warrants direct engagement. Collector vehicles traverse the abyssal plain, removing nodules and resuspending surface sediment. While slow recovery over four decades has been reported based upon trials of first-generation equipment in the 1970s, modern trials have demonstrated a significantly reduced impact footprint, and positive signs of recovery within 12 months.<sup>57</sup> The regulatory response is structured, sequential, and precautionary in design. Baseline surveys establish pre-disturbance conditions. Pilot collection trials generate empirical impact data at limited scale before commercial operations are authorized. Adaptive management requirements allow regulators to adjust or halt operations based on observed effects. Closure plans and restoration

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<sup>57</sup> <https://www.nature.com/articles/s41559-025-02965-4#citeas>

The Metals Company. Environmental Impacts of Polymetallic Nodule Collection: What does the data tell us?. Research summary. Available at: <https://metals.co/wp-content/uploads/2026/06/Environmental-Overview-Deck-February-2026.Revised.pdf>

obligations extend beyond the operational period. The framework does not eliminate environmental impact, and no industrial activity can. It creates a structured process for characterizing, minimizing, and managing that impact under enforceable federal oversight, rather than allowing unregulated collection to proceed.

MMA is actively building the environmental baseline infrastructure that responsible leasing requires. Working with the National Academies of Sciences, Engineering, and Medicine, the agency is developing environmental baseline information acquisition and assessment standards for critical mineral activities on the Outer Continental Shelf.<sup>58</sup> NOAA's American Samoa mapping initiative adds publicly accessible data on seabed geology and environmental conditions across more than 30,000 square nautical miles of federal waters.<sup>59</sup> Good baseline data is what makes sound permitting possible and what gives the scientific community a factual foundation for ongoing research and review.

The environmental comparison to existing supply chains matters and deserves to be made directly. Roughly 75 percent of the world's nickel now comes from Indonesia, where mining drove the loss of more than 240,000 hectares of rainforest in 2024 alone and contributed to flooding that killed over a thousand people<sup>60</sup>. Roughly 70 percent of cobalt comes from the Democratic Republic of Congo, where child labor in artisanal mining is well documented<sup>61</sup>. Tropical rainforest carries up to 3,000 times the biomass of the abyssal seafloor, where life is scarce and largely microscopic. The choice in front of policymakers is not seabed mining versus no mining. It is seabed mining under American standards versus more of what is happening in Indonesia and the DRC today.

The strategic value of American-aligned standards also extends beyond the operations themselves. When U.S.-permitted projects demonstrate that robust environmental monitoring, baseline characterization, and adaptive management are commercially viable, they establish a performance benchmark that the ISA, allied regulators, and commercial buyers can reference. Standards adopted voluntarily under strong regulatory regimes tend to become the floor that subsequent operators are measured against - not because they are imposed, but because they are demonstrated. The country that operates to the highest standard shapes what 'acceptable' means.

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<sup>58</sup> <https://www.congress.gov/crs-product/R48302>

<sup>59</sup> <https://www.noaa.gov/news-release/noaa-to-map-critical-mineral-deposits-in-deep-waters-off-american-samoa>

<sup>60</sup> <https://earth-insight.org/cnn-9-26-25/#>

<sup>61</sup> <https://www.cobaltinstitute.org/wp-content/uploads/2025/05/Cobalt-Market-Report-2024.pdf> ; <https://scienceinsights.org/what-is-cobalt-mining-and-why-is-it-controversial/>

## SPOTLIGHT

### *Fifty Years of Scientific Investment – Deep Sea Datasets*

Research on the Clarion–Clipperton Zone (CCZ) has been ongoing for over five decades. Since the late 1960s, the region has hosted hundreds of offshore research expeditions, with cumulative investment likely exceeding billions of dollars in environmental studies and mining technology development.



*image source: The Metals Company*

Between 1975 and 1980, NOAA's Deep Ocean Mining Environmental Study (DOMES) program established baseline data for three sites within the CCZ and assessed the potential impacts of real technologies,<sup>62</sup> as well as simulated disturbances. This extensive program culminated in the publication of a final Programmatic Environmental Impact Statement for the CCZ region in 1981.<sup>63</sup> As NOAA reported to Congress in 1995, the

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<sup>62</sup> Extensive historic footage of the DOMES program and pioneer mining trials exists and is available here: [https://youtu.be/Wm-cMqUd97A?si=NL5CWWg8\\_6IAIW1P](https://youtu.be/Wm-cMqUd97A?si=NL5CWWg8_6IAIW1P)

<sup>63</sup> NOAA Final Programmatic Environmental Impact Statement 1981. <https://repository.library.noaa.gov/view/noaa/30035>

DOMES program “basically eliminated, pending verification during monitoring of further at-sea mining system tests, virtually all other environmental concerns which were raised around deep-sea mining.”<sup>64</sup>

Later, NOAA spent the following decades filling the knowledge gaps on sediment plumes identified during DOMES, simulating worst-case scenarios using custom-designed equipment, while making this equipment – and NOAA scientists – available to other international research agencies.

Since pioneer technology trials first took place in the CCZ in the 1970s, companies have conducted several large-scale technology trials to validate and assess the immediate and long-term environmental impacts of their equipment, most recently by The Metals Company in 2022, which collected 3,000 tonnes of nodules while monitoring the environmental impacts. Revisits to this site, as well as that of early pioneer tests and simulated disturbances, have since provided long-term data on seafloor recovery.

Taken together, it is estimated that governments and private entities have collectively dedicated over 9,000 days—equivalent to nearly 25 years—at sea to gather deep-ocean data, with at least the same amount of time spent onshore identifying specimens and analyzing results.

This extensive body of research positions the CCZ among the most thoroughly studied marine regions globally, with hundreds of thousands of scientific papers published and a large amount of the underlying data available via open-source repositories. This body of work provides an opportunity to fill the few remaining knowledge gaps identified in NOAA’s 1981 Programmatic Environmental Impact Statement with modern datasets, and directly addresses the most common concerns about nodule collection:

| TOPIC           | CLAIM                                                                            | FINDING                                                                                                                                                                                                                                                                                          |
|-----------------|----------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Seafloor plumes | Disturbed sediment could travel thousands of kilometers from the collection site | MIT studies show that the plume forms a turbidity current that hugs the seafloor, with 92–98% of sediment remaining below 2 meters; <sup>65</sup> TMC’s test mining data shows 95–98% of mobilized sediment is left directly at the seafloor, with the vast majority (>95%) settling within 1 km |
| Midwater plumes | Discharged return water could spread                                             | Midwater plume resulting from TMC’s commercial system comprises the 2–5% of sediment not                                                                                                                                                                                                         |

<sup>64</sup> NOAA Report to Congress 1995: [https://www.noaa.gov/sites/default/files/2025-08/gcil\\_dsm\\_1995\\_report.pdf](https://www.noaa.gov/sites/default/files/2025-08/gcil_dsm_1995_report.pdf)

<sup>65</sup> Carlos Muñoz-Royo *et al.*, An in situ study of abyssal turbidity-current sediment plumes generated by a deep seabed polymetallic nodule mining preprototype collector vehicle. *Sci. Adv.* 8, eabn1219(2022). DOI: [10.1126/sciadv.abn1219](https://doi.org/10.1126/sciadv.abn1219)

|                             |                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|-----------------------------|------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                             | over 1,000 km and contaminate fisheries                                | separated at the seafloor and dilutes rapidly to background levels within several kilometers; discharge occurs at 2,000 m <sup>66</sup> , far deeper than where tuna and other species live or dive to feed; modeling by Australia's national science agency CSIRO finds that any dissolved metals are highly unlikely to bioaccumulate in commercial fish species <sup>67</sup>                                                                                                                  |
| <b>Noise &amp; light</b>    | Operational emissions could disrupt marine wildlife                    | Noise levels are similar to other marine industries <sup>68</sup> ; TMC data shows that noise above NOAA's behavioral threshold for marine mammals is confined to a 3.8 km radius around the vessel; light is limited to a 200 m radius at the surface and 11 m at the seafloor                                                                                                                                                                                                                   |
| <b>Carbon sequestration</b> | Disturbing abyssal sediment could disrupt carbon sinks                 | Marine sediments host less than 5% of total oceanic carbon sink; a tiny fraction of this sedimentary carbon is stored at abyssal depths, and none can be converted by microbes into CO <sub>2</sub> ; <sup>69</sup> peer-reviewed research published in 2020 finds "trivial" potential impact on carbon sequestration <sup>70</sup>                                                                                                                                                               |
| <b>Biodiversity loss</b>    | Collection could drive extinctions of species still unknown to science | Abyssal plains in the CCZ represent roughly 2% of the abyssal habitat globally; roughly half of the CCZ is already protected, and companies are expected to leave at least 30% of their license areas untouched; decades of deep-sea research also show that most abyssal species are widely distributed <sup>71</sup> , often over thousands of kilometers; exploration by private companies is helping to close remaining taxonomic gaps by significantly increasing sampling across the region |
| <b>Habitat destruction</b>  | Habitat destruction will be inevitable and irreversible                | A study published in <i>Nature</i> demonstrates full recovery of sediment macrofauna and foraminifera 44 years after test mining using legacy technology that disturbed top 80 cm of seafloor sediment <sup>72</sup> .                                                                                                                                                                                                                                                                            |

<sup>66</sup> The Metals Company. Environmental Impacts of Polymetallic Nodule Collection: What does the data tell us?. Research summary. Available at: <https://metals.co/wp-content/uploads/2026/06/Environmental-Overview-Deck-February-2026.Revised.pdf>

<sup>67</sup> Pethybridge H, Fulton EA, Parr JM, Dunstan PK, Rowden AA, Dambacher JM. Modelling ecological impacts of metal bioaccumulation from mid-water plume discharges. Commonwealth Scientific and Industrial Research Organisation. (2025). Available at: <https://research.csiro.au/dsm/wp-content/uploads/sites/569/2025/07/CSIRO-dsm-pelagic-Ecotracer-modelling.pdf>

<sup>68</sup> <https://noduleresearch.com/key-topics/ocean-noise/>

<sup>69</sup> Friedlingstein, P. (2023). Global Carbon Budget 2023. *Earth System Science Data*, 15(12), pp.5301–5369. doi: <https://doi.org/10.5194/essd-15-5301-2023>.

<sup>70</sup> Orcutt, B.N., Bradley, J.A., Brazelton, W.J., Estes, E.R., Goordial, J.M., Huber, J.A., Jones, R.M., Mahmoudi, N., Marlow, J.J., Murdock, S. and Pachiadaki, M. (2020). Impacts of deep-sea mining on microbial ecosystem services<sup>‡</sup>. *Limnol Oceanogr*, 65: 1489–1510. <https://doi.org/10.1002/lno.11403>

<sup>71</sup> McClain CR, Hardy SM. The dynamics of biogeographic ranges in the deep sea. *Proc Biol Sci*. 2010 Dec 7;277(1700):3533–46. <https://doi.org/10.1098/rspb.2010.1057>.

<sup>72</sup> Jones, D.O.B., Arias, M.B., Van Audenhaege, L. *et al.* Long-term impact and biological recovery in a deep-sea mining track. *Nature* **642**, 112–118 (2025). <https://doi.org/10.1038/s41586-025-08921-3>

Studies demonstrate how technical progress has reduced environmental footprints: TMC's collector disturbed the top 3–5 cm of sediment<sup>73</sup>; in just 12 months, pioneer species began to return and positive signs of recovery were observed; microbes making up over 60% of seafloor life showed no impact, while impacts to other organisms were limited to tens of meters and there was no measurable impact beyond 100 m

**“Dark oxygen”**

Polymetallic nodules are a novel source of oxygen, generated by electrolysis

Six published rebuttals<sup>74</sup> find the dark oxygen hypothesis is incompatible with decades of established evidence and is “thermodynamically impossible”; scientists argue the claim is far better explained by the deliberate omission of contradictory data showing oxygen levels rose even in the absence of nodules, and improper equipment use

A clear pattern is observable: speculative claims, while circulating quickly and receiving much media attention, cannot outrun the quality and quantity of data now available. Multiple independent datasets gathered fifty years apart address all major concerns and point to the same conclusion: the environmental impacts of deep-sea mining are manageable and contained within the mining area. Long-term monitoring of initial commercial operations, a regulatory requirement, will further enlarge this evidence base, ensuring this industry advances in lockstep with the accumulation of knowledge.

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<sup>73</sup> The Metals Company. Environmental Impacts of Polymetallic Nodule Collection: What does the data tell us?. Research summary. Available at: <https://metals.co/wp-content/uploads/2026/06/Environmental-Overview-Deck-February-2026.Revised.pdf>

<sup>74</sup> A critical synthesis review of the dark oxygen hypothesis was published in Downes P, Cuesta A, Denny A, Tengberg A, Hall POJ, Trellevik L-K, Svellingen W, Jaspars M, Webber AP, Sales de Freitas F, Bento JP, Marsh L and Clarke M. (2025) Extraordinary claims require extraordinary evidence: evaluating nodule-associated dark oxygen production. *Front. Mar. Sci.* 12:1721853. <https://doi.org/10.3389/fmars.2025.1721853>. Additional pre-print rebuttals by academics and industry experts are available at <https://eartharxiv.org/repository/search/sweetman/>.

## BREAKOUT

### *Setting The Record Straight About Polymetallic Nodule Harvesting*

A few specific concerns about seabed mineral development circulate constantly, and several of them predate the science and regulatory record now available. Here is what that record shows, including where questions remain open.

#### *"It's like strip mining the seafloor."*

Nodule harvesting picks up unattached nodules along with a thin layer of surface sediment, working along defined collector tracks. Polymetallic nodule collection does not remove, overburden, or excavate buried ore. The collector vehicle functions closer to a harvester moving through a field than a bulldozer clearing terrain – it lifts what's already lying on top and leaves the substrate between tracks untouched. Selective harvesting simply picks up individual nodules. Comparing that to strip mining, which removes substantial overburden to access deep ore bodies, describes a fundamentally different process and scale of disturbance – even though collector tracks, when used, do disturb the surface sediment layer and some surrounding area, an impact worth being direct rather than describing as untouched.

#### *"Toxic waste gets dumped back into the ocean."*

Different systems handle this differently. In riser-based operations, the seawater pumped up alongside the nodules – return water – is subject to permit conditions requiring monitoring of dispersal rate and sediment concentration, and NOAA's permitting process is actively grappling with how discharge depth should be regulated, including the midwater plume question. Calling it toxic waste skips past the fact that this is a regulated industrial discharge under active scientific regulatory scrutiny, not something released without oversight or accountability.

Most nodule collection systems transport nodules to the surface using seawater and compressed air. Once dewatered, this seawater – containing only trace, naturally occurring sediment – is released at depths of 2,000 meters or greater, far below most marine life. Data from mining test monitoring shows that this sediment and any trace metal concentrations dilute quickly into the immense volume of the Pacific.

Commercial operations will monitor these parameters in real time, and permits will be written with enforceable limits to keep them in check. Future development of closed-loop riser systems and riser-less collection methods will likely eliminate the midwater plume entirely.

Selective robotic systems do not generate a return-water stream at all; the nodules are carried to the surface by the vehicle that collected them.

In neither case is there an unregulated release of anything.

***"The technology is unproven."***

The seabed mineral industry benefits from decades of innovation in other offshore industries, where deepwater operations are no longer novel. Offshore oil and gas operations have steadily increased operational depth from tens of meters to thousands of meters today, all while meeting strict safety and environmental requirements in some of the world's most demanding environments. Across the technology stack, from dynamically positioned vessels and heavy-lift capabilities to riser systems, remotely operated vehicles, and subsea sensors, none of this is new. What's different is that these well-established systems are being put to use in the development of a new resource frontier.

At the same time, America is driving innovation: AI-driven object recognition, autonomous buoyancy control, and selective collection are U.S.-developed capabilities. Innovators will continue to improve and prove out new technology that drives down cost and impact.

***"The industry remains untested at commercial scale."***

True. But feasibility rests on engineering validation and projected unit economics, not precedent. Pilot collection trials have successfully retrieved material from operational depths. NOAA has active permit applications under review. There have been decades of exploration and scientific research. Pre-feasibility studies are done. Collection systems have been tested at operational depth. What's missing is the first commercial run — which is where the industry currently sits, ready to test whether projections translate to sustained operations.

***"The U.S. is violating international law."***

The U.S. is not violating international law. U.S. is permitting runs under the Deep Seabed Hard Mineral Resources Act, a statute Congress passed in 1980 and that has governed American seabed activity for over four decades. This framework predates the United Nations Convention on the Law of the Sea (UNCLOS) and the International Seabed Authority's regime. The validity of licenses awarded under DSHMRA was recognized by several other industrialized nations, including the UK, Germany, France, the Netherlands, Belgium, Italy, Japan, and China, through multiple bilateral treaties. The U.S. never signed UNCLOS and has persistently objected to its seabed mineral provisions, maintaining for over four decades that the recovery of seabed minerals in international waters remains a high seas freedom under customary international law, available to all states.

Some companies have instead sought exploration contracts through the ISA, operating under its regulatory process. Both the DSHMRA and ISA frameworks currently exist side by side, and companies have pursued licenses under each.

***"A moratorium is the responsible choice."***

The argument put forward by NOAA to Congress in 1981 remains as relevant today as it did back then. Prohibiting or delaying deep-sea mining would lead to substantial adverse effects resulting from increased land-based mining and an increasing dependence on foreign supplies of strategic metals. But while in 1981 the sources of supply were more diverse, today's metal supply chains – from mined ore to finished products – are overwhelmingly controlled by China. Development of abundant seabed mineral resources under well-established U.S. regulatory standards requiring strict environmental performance and monitoring would secure U.S. technological leadership on this new and strategic resource frontier and create tens of thousands of quality jobs across the entire industry ecosystem.

Moreover, a U.S. moratorium doesn't reduce global demand for cobalt, nickel, or manganese – it just means that demand continues to be met by the sources already supplying it today, largely large-scale industrial mining in the Democratic Republic of Congo and nickel processing in Indonesia, both operating under materially less oversight than U.S. permitted operation would. Development under U.S. regulatory standards, with continuous environmental monitoring built into the permit, gives regulators and the public visibility that the current dominant supply chains don't offer. That's a meaningfully different risk profile – not a guarantee of zero impact, but a structurally more accountable one.

The offshore energy sector has spent decades proving that industrial-scale operations and serious environmental performance aren't at odds with each other. Deep-sea mineral development is the next test of that record, not an exception to it.

***"Extracting Minerals from the Ocean will Destroy it"***

All mineral extraction has environmental impacts. The relevant question is not whether impacts exist, but their magnitude, duration, geographic extent, and how they compare with available alternatives. That is why environmental assessments evaluate seabed development against existing terrestrial supply chains rather than against a no-impact baseline that no form of mineral production can achieve.

***"We don't know enough about the deep ocean."***

The deep ocean remains one of Earth's least studied environments, and many scientific questions remain. That is precisely why modern exploration programs

devote years to baseline environmental studies before any collection testing begins. The purpose of exploration is not simply to locate minerals—it is to characterize ecosystems, understand environmental conditions, and generate the data regulators need to evaluate future activities. Continued research reduces uncertainty; it does not eliminate the need for careful oversight.

***"Recycling means we won't need new mines."***

Recycling will become an increasingly important source of critical minerals, but it cannot satisfy projected demand on its own. Most batteries, wind turbines, and electric vehicles currently in service have not yet reached the end of their useful lives, limiting the volume of material available for recycling over the next several decades. Most long-term supply analyses conclude that recycling complements rather than replaces primary production.

## SPOTLIGHT

### *ABS Risk Management Starts At the Beginning*

The seafloor holds enormous quantities of the same metals, and the push to go get them is no longer theoretical. That raises a question with no real precedent: how do you manage the risks of an offshore mining system deep underwater, far from onshore resources?

That's the question the American Bureau of Shipping (ABS), the same classification society that has certified oil rigs, tankers, and offshore platforms for more than a century, set out to answer with a new rulebook specifically for subsea mining.

The approach is to catch problems on paper, before they become problems in the ocean. Every mining vessel has to pass review on the basics — the hull, the equipment that holds it in position, the onboard machinery — before it's allowed to operate. But ABS goes further and requires something most industries don't: a formal hazard study, done before construction even starts, where engineers have to walk through every plausible way the system could fail and build fixes into the design itself, not bolt them on afterward. For genuinely new technology with no track record, there's a separate process that requires manufacturers to actually demonstrate, through testing, that an untested design is as safe as one with decades of service behind it. Nothing gets the benefit of the doubt.

And it doesn't stop at the blueprint stage. Hoses and cables carrying fluid and power down to the seafloor get pressure-tested at multiples of what they'll ever actually see in service. Lifting gear gets proof-tested under real weight before it's approved, and tested every five years again. For the equipment that lives underwater permanently, those five-year checks require pulling it back up to the surface so an inspector can actually look at it.

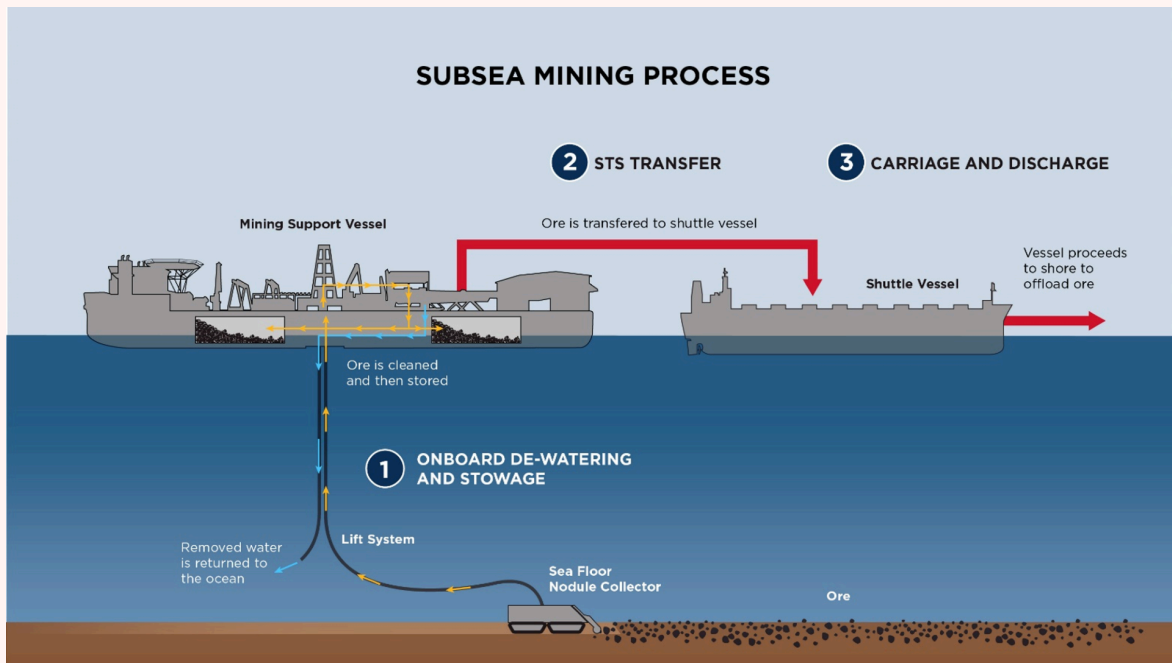


*image source: ABS*

A standard like this gives policymakers, insurers, and the public something concrete to point to: proof that going after these minerals doesn't require choosing between economic urgency and operational safety.

## BREAKOUT

### *Deeper Waters, Lower Impact: How Operational Separation and Modern Technology Reduce Risks for Commercial Fisheries*

The concern that polymetallic nodule operations could impact fisheries comes up consistently, but fundamentally these industries do not compete for the same water.

In many cases, the physical remoteness of regions prospective for nodules means that local fishing activity is minimal, reducing the potential for spatial overlap with seabed mineral operations. In the Clarion Clipperton Zone (CCZ), one of the regions of greatest commercial interest, fishing activities represent less than 2% of fishing hours globally.<sup>75</sup>

And though some argue that the midwater release of trace, naturally occurring sediment entrained in the seawater used by most systems to lift nodules to the surface could impact thinly and widely distributed fisheries, the extreme vertical separation from seabed mineral operations provides a significant buffer.<sup>76</sup> Companies intend on discharging this sediment at depths of at least 2,000 meters, far below where key species like tuna and billfish live and breed in the top few hundred meters.

Technological progress has also greatly limited the amount of sediment lifted to the surface in the first place. During test mining, TMC's collector proved highly efficient at separating sediment from the nodules, with between 95-98% of sediment being left directly at the seafloor.

Less sediment going up means less to come down. Test mining data show that sediment released at 2,000-meter water depth dilutes rapidly into the vastness of the Pacific Ocean, with concentrations approaching a grain of sand in a liter of water after several kilometers,<sup>77</sup> while trace metal concentrations dilute equally fast.

As this industry grows and new technologies develop with it, it is likely that the development of closed-loop risers or other systems will eliminate the need to release these relatively small amounts of sediment into the midwater entirely.

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<sup>75</sup> <https://isa.org/im/publications/technical-study-33-potential-interactions-between-fishing-and-mineral-resource-related-activities-in-areas-beyond-national-jurisdiction-a-spatial-analysis/>

<sup>76</sup> [https://dsm.gsd.spc.int/public/files/reports/SPCNIWA\\_Report\\_FINAL231116.pdf](https://dsm.gsd.spc.int/public/files/reports/SPCNIWA_Report_FINAL231116.pdf)

<sup>77</sup> The Metals Company. *Environmental Impacts of Polymetallic Nodule Collection: What does the data tell us?* Research summary. Available at: <https://metals.co/wp-content/uploads/2026/06/Environmental-Overview-Deck-February-2026.Revised.pdf>

## BREAKOUT

### *Biodiversity and Habitat*

The concern about the potential for deep-sea mining to drive biodiversity loss is one of the most commonly raised objections to deep-sea mineral development. It deserves a serious answer, and the science that has accumulated over the past decades provides one.

Tremendous biological research has gone into regions like the Clarion-Clipperton Zone (CCZ) for over 50 years, with hundreds of offshore research expeditions and cumulative investment in the billions. Between 1975 and 1980, the U.S. Government and National Oceanic and Atmospheric Administration (NOAA) began work on the Deep Ocean Mining Environmental Studies (DOMES) project, one of the most comprehensive marine science studies ever,<sup>78</sup> establishing baseline data across multiple sites in the CCZ, and monitoring pilot mining trials. Upon completion of these studies and the preparation of a Programmatic Environmental Impact Statement for the entire CCZ region,<sup>79</sup> NOAA reported to Congress that environmental concerns relating to commercial mining had been all but eliminated.<sup>80</sup>

Research then expanded greatly in the decades that followed, with governments, research institutions, and private companies spending more than 9,000 days – or roughly 25 years – at sea, assessing biodiversity and potential mining impacts, from seafloor to surface. The concern that industry is sailing into the unknown is not consistent with the clarity provided by over half a century of scientific evidence.

Studies to date have documented clear signs of recovery, on timeframes determined by the technology used. A 2025 study by researchers from the Natural History Museum London and MIT revisited the site of a 1970s mining test 44 years after disturbance by a first-generation system that used a propulsion system that ploughed 80-cm-deep furrows in the seafloor. They found full recovery of microscopic organisms in the collector's tracks and in areas covered by the sediment plume, which had no impact.<sup>81</sup> Subsequent trials using current-generation technology that disturbs only the top 3-5 centimeters of the seafloor have documented positive signs of recovery within 12 months: mining had no impact on the community composition of microbes that make up 60% of seafloor life, while impacts to other organisms were limited to just tens of meters.<sup>82</sup> These ecosystems recover. Recovery of larger, slower-growing sessile organisms is a longer process and

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<sup>78</sup> Extensive historic footage of the DOMES program and pioneer mining trials exists and is available here: [https://youtu.be/Wm-cMqUd97A?si=NL5CWVWg8\\_6IAIW1P](https://youtu.be/Wm-cMqUd97A?si=NL5CWVWg8_6IAIW1P)

<sup>79</sup> NOAA Final Programmatic Environmental Impact Statement 1981. <https://repository.library.noaa.gov/view/noaa/30035>

<sup>80</sup> NOAA Report to Congress 1995: [https://www.noaa.gov/sites/default/files/2025-08/gcil\\_dsm\\_1995\\_report.pdf](https://www.noaa.gov/sites/default/files/2025-08/gcil_dsm_1995_report.pdf)

<sup>81</sup> Jones, D.O.B., Arias, M.B., Van Audenhaege, L. *et al.* Long-term impact and biological recovery in a deep-sea mining track. *Nature* **642**, 112–118 (2025). <https://doi.org/10.1038/s41586-025-08921-3>

<sup>82</sup> The Metals Company. Environmental Impacts of Polymetallic Nodule Collection: What does the data tell us?. Research summary. Available at: <https://metals.co/wp-content/uploads/2026/06/Environmental-Overview-Deck-February-2026-Revised.pdf>

remains an active research question, and emerging technologies may result in even better recovery rates.

The scale of operations also matters. The CCZ represents less than 2% of the available abyssal habitat globally, and almost half of the entire CCZ is permanently protected from any mining activity. Operators will also likely leave up to half of their mining areas untouched. The result is that even if all areas under U.S. application or international exploration contracts moved into production simultaneously, nodule collection would transform approximately 0.5 percent of the global seafloor, leaving a mosaic of various habitat types commonly found across the abyssal plains.

Decades of research show that most abyssal species are widely distributed, with connectivity extending across thousands of kilometres.<sup>83</sup> While some level of risk is always present, given the large areas set aside for protection, these risks are inherently low, and persistent monitoring by a growing pool of seabed mineral contractors will ensure that our understanding of these risks is continuously updated as commercial operations expand.

Against that backdrop, a nodule operation with designated no-take zones and monitored collection corridors is a managed footprint in one of the largest environments on earth.

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<sup>83</sup> McClain CR, Hardy SM. The dynamics of biogeographic ranges in the deep sea. *Proc Biol Sci.* 2010 Dec 7;277(1700):3533–46. <https://doi.org/10.1098/rspb.2010.1057>.

## SPOTLIGHT

### *What Allies Are Already Building – The EMINENT Project*

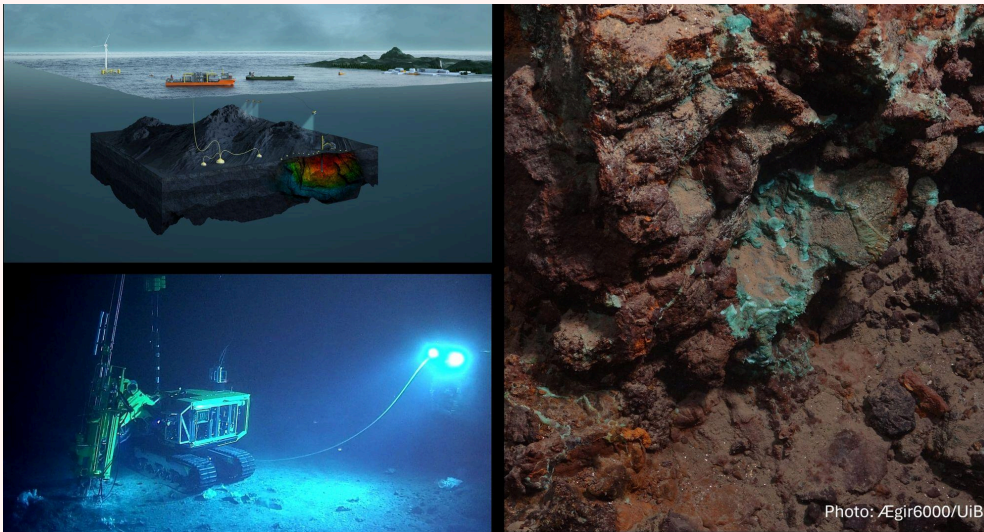


image source: [eminent-project.com](https://www.eminent-project.com/)

While work moves ahead in the U.S., partners in Europe are pushing forward on their own piece of the puzzle: processing seabed minerals responsibly once they reach shore. The Norwegian-backed EMINENT project, funded through the government's Green Platform initiative, developed beneficiation methods for seabed minerals, aiming to recover metals at high yield while cutting ecological footprint by 80 percent compared to land-based mining. It pairs that work with continuous environmental baselines monitoring and exploration technology designed to locate deposits with minimal seabed disturbance. The project concluded in February 2026.

It's a useful marker of how much serious technical and environmental groundwork U.S.-aligned efforts are putting into this industry, on both sides of the Atlantic. As extraction and permitting progress in American waters, complementary processing research like EMINENT's adds to a deepening base of environmental science and engineering know-how that the broader effort can draw on.

Learn more about the EMINENT Project: <https://www.eminent-project.com/>

## SPOTLIGHT

### *How Moana Minerals Works With the Cook Islands*

Moana Minerals has built its exploration program around the idea that community input should actually change how the work runs, not just get collected and filed. The company frames its presence around Cook Islands tradition and the culture's close connection to the ocean, using an adaptive management process to fold local feedback back into its operations.

That shows up on the water, too. The company's exploration vessel, the MV Anuanua Moana, is owned and run by sister company Kiva Marine and based in the Cook Islands rather than chartered in from abroad. Its crew handles everything from routine bathymetric surveys to ROV transects at 6,000 meters, deepwater work more than 300 miles north of Rarotonga that few vessels in the region are equipped to do.<sup>84</sup>

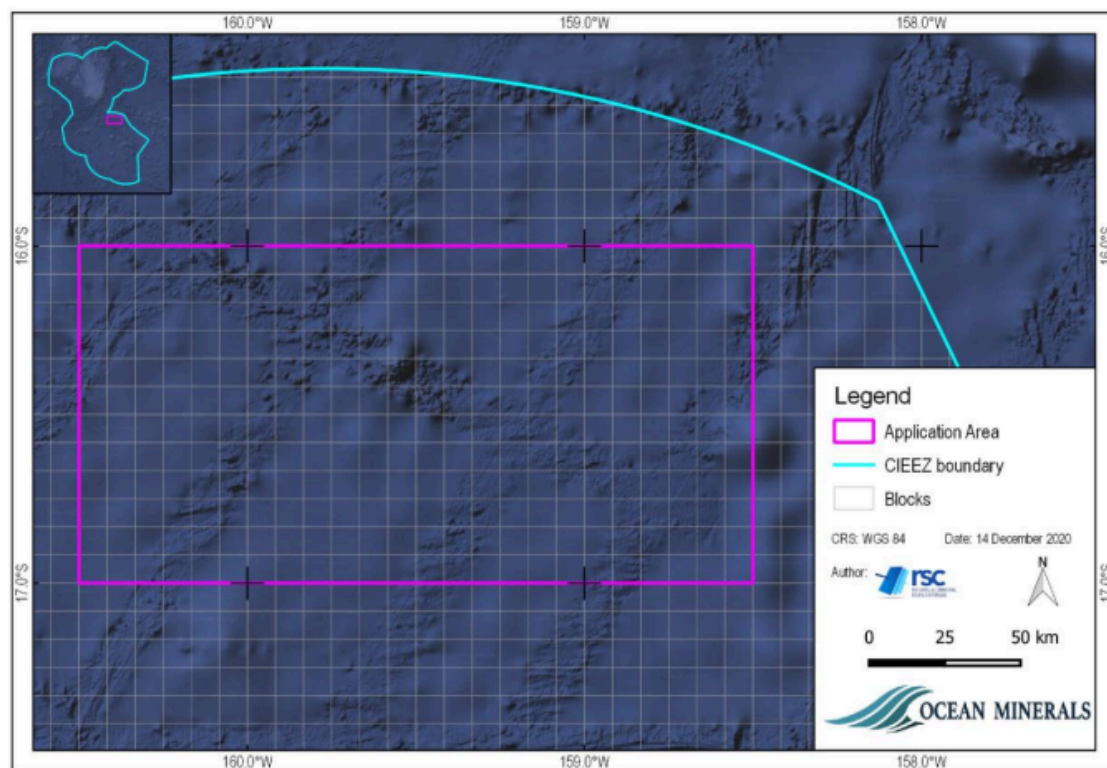


*Figure 1 - Exploration License Application Area encompassing OML reserved areas*

<sup>84</sup> <https://static1.squarespace.com/static/5cca30fab2cf793ec6d94096/t/6187022f0fa6a109fcd3f307/1636237874582/Moana+Minerals+Ltd+NTS.pdf>

The jobs case is the most direct community benefit. Moana sources equipment and services through existing island industries and has built training pathways for mariners, electricians, mechanics, engineers, and geologists – work that lets Cook Islanders build a career at home instead of leaving for New Zealand. The company also ties its work to the Cook Islands' own economic diversification goals, offering a revenue stream separate from tourism and fishing. Moana is still in the exploration and environmental-assessment phase, not production, but the model is already taking shape: local vessels, local hiring, and local training ahead of any commercial harvest – investments and capabilities that will remain as exploration transitions to commercial production.



Source: <https://www.moanaminerals.com/community>

## BREAKOUT

### *What This Industry Has Taught Us About the Deep Ocean*

Most of what is known was paid for by this industry. Over the last sixty years, private investment in seabed minerals has funded the large majority of deep-ocean biological and geological survey work. The Ocean Biodiversity Information System now hosts open-access data covering more than 125 million observations across nearly 200,000 species. The ISA's DeepData repository, launched in 2019, holds over 10 terabytes gathered from dozens of private company cruises and has been cited in more than 160 scientific publications.

That research has corrected the record as often as it has confirmed it. MIT researchers found that sediment disturbance from conventional collection ran one-third to one-sixth of what critics had hypothesized, and that plumes did not rise hundreds of feet above the seafloor as predicted. During a single 2021 collection trial, independent scientists deployed roughly 200 instruments across 43 platforms to monitor the campaign, a sensor network nearly as complex as the system it was watching.

The next generation of survey capability is coming from the same place. Autonomous underwater robots substantially improve the accuracy of biodiversity measurement while entirely avoiding the destructive sampling that has historically characterized deep-sea biological survey. For decades, characterizing abyssal fauna meant trawling it to the surface. These systems operate over long distances at extreme depth, expanding the geographic and temporal reach of ocean observation well beyond what crewed or surface-tethered platforms can achieve. And the cameras and sensors that selective collection requires in order to function generate novel data on species, habitats, and seafloor geology as a byproduct of commercial operation.

The same technology that makes responsible collection possible makes non-destructive deep-sea survey possible, at a scale no research budget has ever funded.

## BREAKOUT

### *Working with Host Communities*

Unlike land-based minerals that are near local communities, ocean mineral development happens offshore. Engaging port communities and island residents remains essential.



*image source: The Metals Company*

These communities will see economic impacts: local provisioning of ship operations and crew, emergency and standby vessel support, port facility utilization, environmental monitoring contracts, and onshore testing and sample handling. In other offshore sectors, a portion of federal revenues are shared with adjacent states.

At the same time, many residents have concerns about the potential environmental impacts or effects on fishing enterprises. As a new industry, it is incumbent on all companies and stakeholders to understand these concerns and the importance of the ocean to local communities, to share information and accurate data showing the low expected impacts of seabed mining, to continually monitor and research as operations advance to validate these early findings, and to innovate and continually improve.

## Safety at Sea Crew and Vessel Safety in Ocean Mineral Operations

Managing risk has always been a priority of offshore work. The energy industry learned that lesson across decades of deepwater operations, and the standards it developed, vessel safety management systems, stop-work authority, emergency response protocols, crew training regimes, represent some of the most rigorous occupational safety frameworks in any extractive industry. Ocean mineral development is inheriting that infrastructure, not starting from scratch.

The companies advancing seabed mineral collection operate under layered international safety frameworks: the International Maritime Organization's Safety of Life at Sea (SOLAS) Convention, the International Convention for the Prevention of Pollution from Ships (MARPOL), and International Labour Organization standards that govern seafarer health and working conditions. These are strong requirements for any vessel operating in international waters, enforced through flag state inspection regimes and port state controls. These conventions establish internationally recognized requirements for vessel design, lifesaving equipment, fire protection, navigation, pollution prevention, emergency preparedness, crew competency, and seafarer welfare.

Beyond regulatory compliance, the leading operators have adopted what the industry calls a Zero Harm culture, a management philosophy that treats any injury or unsafe condition as a system failure to be investigated and corrected, not an acceptable cost of doing business. Central to this approach is stop-work authority: every worker, regardless of rank or role, has both the right and the responsibility to halt an operation if they identify an unsafe condition. That principle, now standard across offshore oil and gas, is embedded in the safety management systems of ocean mineral operators. Stop-work authority is designed to ensure that safety decisions can be made immediately at the point of work without waiting for management approval when hazardous conditions are identified.

The remote nature of ocean operations, such as vessels working thousands of miles from shore, in areas with limited coast guard coverage, makes proactive safety culture more important, not less. Equipment failures at 4,000 meters cannot be quickly remedied from a port facility. Crew training, hazard identification, and robust maintenance protocols are the primary lines of defense, and the industry's investment in them reflects that reality. Redundancy is therefore built into critical systems, including power generation, communications, navigation, and dynamic positioning, reducing the likelihood that a single equipment failure compromises vessel safety.

## Washington is Moving

On April 24, 2025, President Trump signed Executive Order 14285, "Unleashing America's Offshore Critical Minerals and Resources."<sup>85</sup> The order directed the National Oceanic and Atmospheric Administration (NOAA) to expedite the review and issuance of seabed mineral exploration licenses and commercial recovery permits under the Deep Seabed Hard Mineral Resources Act (DSHMRA), directed the Bureau of Ocean Energy Management (BOEM) to accelerate critical mineral leasing on the Outer Continental Shelf, and established a whole-of-government posture toward ocean mineral development that had been absent from federal policy for decades. It was a clear statement of presidential priority, and it set in motion a series of agency actions that have materially changed the operating environment for the industry since its signing.

### EXECUTIVE ORDER 14285:

#### Unleashing America's Offshore Critical Minerals and Resources

*Signed April 24, 2025*

The most expansive federal commitment to offshore mineral development in American history, EO 14285 establishes U.S. leadership in seabed mineral development as an explicit national priority and sets concrete agency directives across the federal government.

Core mandate: Rapidly develop domestic capabilities for the exploration, characterization, collection, and processing of seabed mineral resources – both on the U.S. Outer Continental Shelf and in international waters under the Deep Seabed Hard Mineral Resources Act.

#### Key directives:

- Secretary of Commerce to assess private sector opportunities for seabed mineral processing capacity in the U.S. or on U.S.-flagged vessels
- Secretary of War to support domestic processing capability development
- Feasibility study on international benefit-sharing for resources extracted in areas beyond national jurisdiction
- Department of the Interior (DOI) is directed to identify authorities to accelerate critical mineral leasing on federal lands and the OCS

<sup>85</sup> <https://www.whitehouse.gov/presidential-actions/2025/04/unleashing-americas-offshore-critical-minerals-and-resources/>

NOAA moved quickly. On January 21, 2026, the agency issued a final rule revising its deep seabed mining regulations under DSHMRA, creating a consolidated application process that allows eligible applicants to apply for exploration licenses and commercial recovery permits simultaneously rather than sequentially.<sup>86</sup> The prior two-step process had not been substantively updated since the agency issued its last exploration licenses in 1984. The revised framework reflects four decades of scientific and technological progress while maintaining the environmental review and oversight requirements that responsible permitting demands. Following the executive order and the revised regulations, NOAA has received over ten DSHMRA applications — a pipeline that did not exist at a meaningful scale before 2025.<sup>87</sup>

BOEM is working on the domestic side of the same equation. The agency has initiated the leasing process for potential mineral lease sales in federal waters offshore of American Samoa, the Commonwealth of the Northern Mariana Islands, Virginia, and Alaska — four separate leasing processes now underway simultaneously, representing the first time BOEM has moved toward hard mineral leasing at this scale.<sup>88</sup>

BOEM is also developing a National Offshore Critical Minerals Inventory in collaboration with USGS and NOAA, systematically locating and assessing mineral deposits across U.S. federal seabed to build the data foundation that responsible leasing decisions require.

The American Samoa mapping initiative adds another significant data layer. NOAA announced a survey covering more than 30,000 square nautical miles of federal waters, beginning in early 2026, generating publicly accessible data on seabed geology, environmental conditions, and mineral prospectivity.<sup>89</sup> That kind of baseline data is what makes responsible permitting possible and what gives investors the geologic confidence to commit capital to exploration before permit applications are filed.

On the financing side, Project Vault puts federal commitment behind the demand signal. The \$10 billion Export-Import Bank program creates a demand-led strategic reserve covering all 60 minerals on the USGS Critical Minerals List; manufacturers identify needed materials and commit to long-term purchase agreements; the reserve then backstops availability during supply disruptions.<sup>90</sup>

For companies evaluating whether to invest in seabed exploration and domestic processing infrastructure, that kind of offtake visibility matters as much as the permitting framework itself. It answers the investor question that has historically slowed capital formation in new extractive sectors: who the customer is, and how committed they are.

Congress is engaged on both sides of the issue, which is itself a sign that the sector has moved from fringe to mainstream policy consideration. Several members have introduced legislation that would codify Executive Order 14285:

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<sup>86</sup> <https://www.federalregister.gov/public-inspection/2026-01044/deep-seabed-mining-exploration-license-and-commercial-recovery-permit-applications>

<sup>87</sup> <https://www.congress.gov/crs-product/IF12608>

<sup>88</sup> <https://www.congress.gov/crs-product/IF13226>

<sup>89</sup> <https://www.noaa.gov/news-release/noaa-to-map-critical-mineral-deposits-in-deep-waters-off-american-samoa>

<sup>90</sup> <https://www.exim.gov/news/week-review-project-vault-and-strategic-critical-mineral-reserve>

- H.R. 3803 in the 119th Congress would lock in the expedited permitting directives as statutory requirements rather than executive policy.<sup>91</sup>
- H.R. 4018, the Unleash America's Offshore Critical Minerals and Resources Act, would codify Executive Order 14285 directly, requiring Interior to establish an expedited process for reviewing prospecting permits and granting OCSLA leases within 60 days of enactment and to develop a priority seabed mapping plan on the same timeline.
- S. 2860 would direct federal agencies to report on U.S. seabed mineral processing capacity and support domestic processing development.<sup>92</sup>

House Natural Resources and House Science, Space, and Technology subcommittees have both held hearings focused on regulatory barriers and strategic positioning for American companies. NOAA's FY2026 budget request also explicitly identified expediting deep seabed mining review as an objective for FY2026 through FY2030, embedding the priority in the agency's five-year planning horizon.

The regulatory architecture is not complete. The permit applications now in NOAA's queue will take time to review. The BOEM leasing processes are in early stages. The processing infrastructure investment that would make domestic development fully self-contained has not yet been committed. But the direction is clear, the agency actions are real, and the policy environment that existed five years ago, when ocean minerals were a theoretical conversation in Washington, no longer exists. The U.S. is no longer asking whether ocean minerals matter. It is working through the practical steps of developing them.

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<sup>91</sup> <https://www.congress.gov/bill/119th-congress/house-bill/3803>

<sup>92</sup> <https://www.congress.gov/bill/119th-congress/house-bill/4018>

## BREAKOUT

### *Who Governs and Where: A Plain Language Guide to Offshore Jurisdictions*

The regulatory picture for seabed mineral development is determined primarily by geography: where the deposit sits determines who has authority over it. Three distinct jurisdictional zones matter, each with its own legal framework and governing body.

#### **U.S. Outer Continental Shelf (OCS):**

Seafloor beneath U.S. federal waters, generally extending from 3 to 200+ nautical miles from shore

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**Who governs:** Bureau of Ocean Energy Management (BOEM), U.S. Department of the Interior (DOI)

**Legal framework:** Outer Continental Shelf Lands Act (OCSLA)

**How it works:** BOEM has authority to lease submerged federal lands for mineral development. Companies must obtain a lease, then submit delineation, testing, and mining plans for approval. The Bureau of Safety and Environmental Enforcement (BSEE) oversees compliance and environmental protection during operations.

**Status:** BOEM has initiated leasing processes for American Samoa, the Commonwealth of the Northern Mariana Islands, Virginia, and Alaska, the first hard mineral lease sales to move forward under this authority.

#### **U.S. Exclusive Economic Zone (EEZ) Territories**

Federal waters surrounding U.S. territories beyond the OCS baseline

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**Who governs:** BOEM (leasing); NOAA (scientific assessment and mapping)

**Legal framework:** OCSLA; relevant territory-specific statutes

**How it works:** Same BOEM leasing framework as the OCS. U.S. territories including American Samoa and the Northern Mariana Islands have EEZs with significant nodule and crust mineral potential. NOAA's 2026 American Samoa mapping initiative – covering more than 30,000 square nautical miles – is building the baseline data future leasing decisions will rest upon.

**Status:** Active leasing processes underway. NOAA mapping initiative launched early 2026.

## Areas Beyond National Jurisdiction (ABNJ)

International waters — beyond any nation's 200-nautical-mile EEZ

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*Two parallel frameworks apply here, depending on whether a country has ratified UNCLOS:*

### ***For UNCLOS member nations:***

**Who governs:** International Seabed Authority (ISA), established under the UN Convention on the Law of the Sea (UNCLOS) in 1994

**How it works:** The ISA issues exploration contracts to companies sponsored by member states and is developing exploitation regulations — a mining code — that will govern commercial recovery. Seventeen exploration contracts for polymetallic nodules are currently in force in the Clarion-Clipperton Zone (CCZ).

### ***For the United States:***

**Who governs:** NOAA, under the Deep Seabed Hard Mineral Resources Act (DSHMRA)

**Legal framework:** DSHMRA (P.L. 96-283), enacted by Congress in 1980

**How it works:** Because the United States is not a party to UNCLOS, it cannot itself sponsor an applicant to the ISA, though U.S.-affiliated companies have applied for and received exploration permits from the ISA through sponsorships from American allies. Separately, NOAA issues exploration licenses and commercial recovery permits to U.S. companies for operations in international waters under DSHMRA, the only fully developed national regulatory framework of its kind. American companies may also operate in allied-nation exclusive economic zones under those nations' domestic frameworks, or partner into existing allied contract areas to conduct testing where environmental baselines already exist. Following Executive Order 14285 and NOAA's January 2026 regulatory update, NOAA has received over ten DSHMRA applications.

**Status:** Active permit pipeline. NOAA has reportedly received more than ten applications since 2025; as of mid-2026, five had been published in the Federal Register as fully compliant.

## Allied-Nation EEZs

Waters within the jurisdiction of U.S. partner nations

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**Who governs:** The sovereign nation — its own domestic regulatory authority

**How it works:** Countries including the Cook Islands, Norway, and Japan have developed their own seabed mining regulatory frameworks governing activity within their EEZs. U.S. companies can operate in allied-nation EEZs under those nations' domestic frameworks — without ISA involvement and without DSHMRA applying. The Cook Islands passed a

comprehensive Seabed Mining Act in 2009, established a Seabed Minerals Authority, and has been issuing exploration licenses since 2013. U.S. companies, including Ocean Minerals LLC, hold active exploration rights there.

**Status:** Active exploration licensing in the Cook Islands. Norway is advancing EEZ mineral assessment. Japan conducting state-backed nodule exploration in the northwest Pacific.

*The regulatory complexity reduces to one practical question for any project: where is the deposit? U.S. territorial and OCS waters go through BOEM. International waters go through NOAA under DSHMRA for U.S. companies, or through the ISA for companies sponsored by UNCLOS member states. Allied-nation EEZs go through that nation's domestic authority. Each lane has a functioning regulatory framework. American companies have access to all three. The DSHMRA and ISA pathways differ in one material respect: an ISA contract carries recognition among UNCLOS States Parties that a DSHMRA permit does not, and the two regimes have already conflicted in practice over the same seabed.*

## First Mover Advantage:

### *Why American Engagement in Seabed Governance Matters*

In 1984, NOAA issued the first U.S. licenses to explore the seabed for minerals. The International Seabed Authority (ISA), the body now writing the rules for that same activity, didn't exist yet. It wouldn't for another decade. Two of those original licenses are still active today.<sup>93</sup>

ISA has issued exploration contracts across the world's oceans, including 17 in the Clarion-Clipperton Zone (CCZ), but has not completed the mining code that will set the environmental standards, royalty structures, and operator obligations for actual extraction.<sup>94</sup>

There is an opening for U.S. leadership. The countries and companies building real operational experience now — generating environmental data, testing equipment, establishing a track record in the field — are the ones positioned to shape what those final rules actually look like.

The U.S. has more standing here than is commonly understood. The Deep Seabed Hard Mineral Resources Act (DSHMRA) gave the National Oceanic and Atmospheric Administration (NOAA), which is part of the Department of Commerce, authority to issue seabed mineral licenses in 1980, fourteen years before the ISA existed.<sup>95</sup>

DSHMRA provides a working regulatory system with documented permitting history, environmental review requirements, and active federal oversight. NOAA issued exploration licenses in 1984 that remain active today, and in January 2026 finalized updated rules introducing a consolidated application process that allows companies to seek exploration authorization and a commercial recovery permit simultaneously. Before issuing either, NOAA is required to produce an environmental impact statement under the National Environmental Policy Act (NEPA). Operations are also subject to the Marine Mammal Protection Act and Clean Water Act provisions covering vessel discharges.

NOAA updated its regulations in January 2026 and has received more than ten applications since Executive Order 14285, Unleashing America's Offshore Critical Minerals and Resource.<sup>96</sup> As of mid-June 2026, five applications had been published in the Federal Register as fully compliant.<sup>97</sup>

The U.S. sits outside the United Nations Convention on the Law of the Sea (UNCLOS), which limits its formal ISA vote, but influence in this domain runs through operational presence, scientific credibility, allied relationships, and the standards that American-led projects demonstrate in practice. None of those require a seat at the ISA table.

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<sup>93</sup> <https://oceanservice.noaa.gov/deep-seabed-mineral-resources/deep-seabed.-mining/>

<sup>94</sup> <https://www.congress.gov/crs-product/IF12608>

<sup>95</sup> <https://oceanservice.noaa.gov/deep-seabed-mineral-resources/deep-seabed-mining/>

<sup>96</sup> <https://www.congress.gov/crs-product/R47324>

<sup>97</sup> <https://oceanservice.noaa.gov/deep-seabed-mineral-resources/deep-seabed-mining/>

Allied engagement is already moving ahead. Norway has parliamentary authorization for continental shelf mineral exploration<sup>98</sup>. Japan is running a state-backed program testing rare-earth mud and nodule recovery in the northwest Pacific.<sup>99</sup> The Cook Islands adopted its first dedicated seabed-minerals legislation in 2009 and subsequently replaced it with the Seabed Minerals Act 2019, amended in 2024. It has established a dedicated Seabed Minerals Authority, developed supporting regulatory and environmental-management frameworks, and issued national exploration licenses. This makes the Cook Islands one of the most established national seabed-minerals jurisdictions among Pacific Island states.

The U.S. and Cook Islands announced formal cooperation on seabed mineral development in August 2025, followed by a NOAA mapping expedition to the Cook Islands continental shelf that October.<sup>100</sup> The partnership has continued to expand. From July 19 to August 13, 2026, NOAA's Okeanos Explorer is conducting a deep-water expedition in partnership with the Cook Islands Seabed Minerals Authority to map and characterize deep-sea habitats using remotely operated vehicles (ROVs). The expedition advances scientific understanding of the region's deep-sea environments while generating baseline environmental data to support future resource management, scientific research, and informed regulatory decision-making.

American-led or American-aligned companies working in these waters carry American standards with them – on environmental practice, on transparency, on how the industry treats the communities and ecosystems around it. That matters now, while the norms are still being set. A few years from now, it will be a lot harder to change them.

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<sup>98</sup> [https://www.europarl.europa.eu/thinktank/en/document/EPRS\\_ATA\(2024\)757616](https://www.europarl.europa.eu/thinktank/en/document/EPRS_ATA(2024)757616)

<sup>99</sup> <https://oceanographicmagazine.com/news/japan-embarks-on-its-first-deep-sea-rare-earth-mining-expedition/>

<sup>100</sup> <https://www.congress.gov/crs-product/IF12974>

## SPOTLIGHT

### *What the Japan-U.S. Seabed Mining Agreement Actually Does*

On March 19, 2026, in Kingston, Jamaica, the International Seabed Authority (ISA) wrapped another council session without agreement on mining regulations it has been drafting since 1994. That same week, in Washington, Japan signed a Memorandum of Cooperation (MOC) with the U.S. Department of Commerce on deep-sea mineral development, while its delegation in Kingston reaffirmed support for the ISA process the memorandum was designed to complement<sup>101</sup>.

The mismatch matters. Japan is bound by UNCLOS; the U.S. never ratified it and repeatedly acted – notably by its consistent reliance of the Deep Seabed Hard Mineral Resources Act (DSHMRA) – persistent objector to the international seabed regime it established. The MOC is drafted to create no legal obligations that conflict with the treaty, and that restraint is what makes it useful: Japan gains access to American permitting authority and seabed extraction technology. The U.S. gains an allied partner willing to build practical capability while the ISA process continues.

The result is complementarity. No treaty violation, no withdrawal, and no obligation created that conflicts with UNCLOS. It reflects a practical judgment that several UNCLOS parties appear to share: bilateral scientific and commercial cooperation can proceed while the ISA completes its mining code, and doing so builds the operational record that code will need in order to be workable.

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<sup>101</sup> <https://www.justsecurity.org/141654/contracting-commons-japan-seabed-mining/>

## SPOTLIGHT

### *The U.S.-Cook Islands Partnership*

The United States and the Cook Islands have built their seabed minerals relationship on a straightforward premise: the Cook Islands controls one of the most significant untapped mineral resources in the Pacific, and American firms already have the research relationships and technical experience on the ground to help develop it responsibly. That partnership predates the diplomatic formalities — Moana Minerals had been running exploration surveys in Cook Islands waters for years before the two governments established formal diplomatic relations in 2023.

The relationship has since deepened on both the government and commercial tracks at once. Washington and Rarotonga have committed to joint research supporting responsible seabed exploration within the Cook Islands' EEZ, while American-linked companies continue the environmental baseline work, metallurgical testing, and community engagement needed to bring any future development up to a defensible scientific standard. The Cook Islands brings sovereign control over one of the largest undeveloped cobalt and nickel resources anywhere, plus a seabed minerals authority with real regulatory experience dating back to 2009. The U.S. brings offshore research capability, deepwater technology, and capital to make the promise of these resources a reality.

For the Cook Islands, the appeal is economic self-reliance — a new revenue stream that lessens its reliance on tourism and fishing, and local jobs in a sector that keeps trained workers on the islands rather than losing them to New Zealand. For the United States, the appeal is a trusted, transparent partner in a region where mineral supply chains are increasingly contested. Both governments have been careful to describe the relationship as gradual and science-led rather than extraction-first, which is precisely what makes it durable: a partnership built on years of survey work and shared regulatory respect.

## Beyond the Metals

The case for ocean minerals usually stops at supply chains: America needs nickel, cobalt, and rare earths, and the seabed has them. That's true, and it's reason enough to act. But it's also just one part of the story.

Building this industry pays dividends well beyond the minerals themselves.

Start with the technology. Deepwater robotics, subsea sensors, dynamic positioning, riser systems, the same tools that collect nodules also run offshore energy platforms, lay submarine cables, support naval operations, and power ocean science. Every dollar invested in seabed mining will sharpen capabilities the country already relies on – just as decades of offshore energy investment did before it. A stronger ocean minerals sector means a stronger offshore industrial base.

The environmental work also strengthens the case. Responsible ocean mineral development requires mapping the seafloor, tracking sediment and plumes, surveying marine life, and monitoring the water column in detail. That work is adding significantly to the most complete picture of the deep ocean ever assembled – building on decades of public research with commercial-scale survey data at resolutions and durations that academic expeditions rarely achieve. This knowledge benefits fisheries, climate science, conservation, and other stakeholders. And doing this under American-led or American-aligned environmental standards means doing it right.

This is also a chance to deepen alliances that matter for reasons beyond minerals. Seabed cooperation gives the U.S. something real to offer Pacific Island nations, Nordic partners, and Indo-Pacific allies who sit near major deposits. The 2025 cooperation agreement with the Cook Islands shows what this looks like: shared science, shared investment, shared benefit.

It's also a jobs win, plainly. Ocean mineral development runs on the same marine engineers, ROV pilots, surveyors, naval architects, and vessel crews that places like the Gulf of America have trained for fifty years in offshore energy. These are good jobs already rooted in American communities. Growing this industry means more demand for that workforce, more career paths, and a skilled offshore labor force ready for whatever comes next.

And what comes next is the biggest opportunity of all. The ocean covers seventy percent of the planet and remains its greatest untapped frontier. Energy, minerals, aquaculture, biotechnology, carbon storage, undersea infrastructure – the next century of ocean industries is still being written. The thread connecting all of them is operational capability: vessels that can hold station in deep water, robotics that can work the seafloor, sensors that can monitor the water column, and regulatory frameworks that can govern industrial activity in the ocean. Seabed mining builds that platform. The nations that build the technology and set the rules first will lead in all of them. Ocean minerals are where that leadership starts.

The reverse is equally true. Failing to build this industry doesn't preserve the status quo - it cedes the ocean frontier to competitors who are already moving, and locks the U.S. into the same supply dependencies the rest of this book describes. The choice isn't between action and inaction. It's between leading and following.

## BREAKOUT

### *What if America Does Nothing?*

Mining the seabed is only half the supply chain. Processing the ore into usable metal is the other half – and it's the half China has already spent two decades developing. China currently dominates global processing capacity for the battery and magnet minerals found in seabed deposits. It also owns or finances a large share of the cobalt mines in the Democratic Republic of Congo that supply the world today.<sup>102</sup> Mining companies surveyed by RAND were upfront about what that means for nodules: China is already pursuing processing deals before its mining equipment is even in the water.<sup>103</sup> If American or allied companies mine the seabed and ship the ore to Chinese refineries, the new supply does little to change who controls the chain.

And the ground is already moving. China holds five exploration contracts in the Clarion-Clipperton Zone (CCZ) through the International Seabed Authority (ISA) - more than any other nation - covering nodules, sulfides, and cobalt-rich crusts. The country that leveraged its terrestrial mineral dominance into a strategic weapon is building a seabed position to match. If the U.S. does nothing, it is not standing still relative to the competition. It is falling further behind a competitor that understands exactly what is at stake.

That's the scenario if the U.S. sits this out. Other countries and Chinese-backed firms develop seabed mining and processing capacity regardless of what the U.S. decides – the resource and the economic incentive don't disappear because the U.S. declines to participate. What disappears is not only American leverage over where refining capacity is built, but also the opportunity to develop the vessels, technologies, workforce, research institutions, and industrial supply chains that support an emerging blue ocean economy.

A domestic industry brings ore through U.S. ports, smelters, and processors, creating jobs and supply security here. But that outcome is not automatic. Extraction without domestic processing capacity simply reroutes the dependency. The policy choice is whether to build the processing infrastructure, supported by federal incentives and offtake certainty, that makes domestic refining commercially viable. Without that parallel commitment, the risk is that seabed resource flows through foreign refineries regardless of who extracts it.

Standing aside means the same minerals get mined and processed somewhere else, leaving the U.S., at a minimum, exactly as exposed to the next export restriction or price shock as it is today – just with more critical minerals added to the dependency list.

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<sup>102</sup> <https://www.congress.gov/crs-product/R47324>

<sup>103</sup> <https://www.rand.org/pubs/articles/2026/could-deep-sea-mining-break-chinas-grip-on-critical.html>

The competition is no longer simply about who mines the seabed first. It is about who develops the capability to operate routinely in the deep ocean. The same ships, subsea technologies, engineering expertise, and scientific knowledge that support mineral exploration also strengthen broader maritime industries, ocean science, offshore infrastructure, and national security. Countries that invest in those capabilities today are positioning themselves for opportunities that extend well beyond critical minerals.

# ABOUT NOIA

The National Ocean Industries Association – NOIA – serves the offshore oil and gas, wind, carbon storage, and ocean minerals industries and provides value to its members by uniting and advancing the business and professional interests of its members and the industry.

## NOIA MISSION

NOIA represents and advances a dynamic and growing offshore energy industry, providing solutions that support communities and protect our workers, the public and our environment.

## NOIA VISION

NOIA is the sought-after and credible voice, advocate and forum for uniting and advancing the interests of the offshore energy industry, recognized for promoting solutions that provide the energy vital for lifting society in a safe and environmentally sustainable way.