

**Testimony before the
U.S.-China Economic and Security Review Commission**

**Hearing on
“Part of Your World: U.S.-China Competition Under the Sea”**

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The Strategic Significance of an Emerging Seafloor Minerals Sector

Members of the Commission and Commission staff, I thank you for the invitation to testify regarding U.S.-China competition in seafloor mineral exploration and recovery.

The exploration and recovery of seafloor minerals may seem like an obscure and highly speculative realm of economic activity. Nevertheless, the United States must prioritize leadership in this nascent technology sector in light of its weighty implications for the development of naval weapons and platforms, for the pursuit of greater supply chain security across multiple critical minerals, and for the protection of U.S. national interests on the high seas.

Seafloor mineral exploration and recovery techniques and technologies significantly overlap with the race to develop new underwater naval systems. This strong dual-use potential means that even unsuccessful efforts to pursue seafloor minerals in the near term can considerably enhance the warfighting capabilities of participating countries. Mineral exploration and collection on the abyssal seafloor inherently involves the launch, operation, coordination, and recovery of advanced underwater and seafloor vehicles designed for high reliability at extreme depths. Such efforts will, in all likelihood, deliver improved performance of underwater and seabed platforms designed to contest shallower strategic waters like maritime chokepoints, the vicinity of important naval anchorages, and key regions like the Western Pacific and Arctic Oceans.

Simultaneously, seafloor minerals offer the United States an opportunity to improve the country’s supply chain security for four critical minerals at once—nickel, cobalt, manganese, and copper. Seafloor polymetallic nodules or manganese nodules are the seabed mineral resource type closest to viable commercial-scale recovery and contain rich grades of all four of these metals. Preliminary deep sea rare earth mud collection tests conducted by Japan in January

2026,¹ together with periodic discussion of the viability of processing the trace amounts of molybdenum and rare earths in polymetallic nodules, indicate an uncertain potential for seafloor mineral recovery to benefit other critical minerals supply chains. However, several difficult obstacles stand in the way of the U.S. being able to make meaningful use of seafloor minerals.

First, companies in this sector have yet to demonstrate nodule collection systems at full commercial scale for an extended period, while onshore metallurgical processing flowsheets for recovered nodules similarly remain incompletely demonstrated. Unreliable nodule collection systems prone to outages could in theory compromise the economics of seafloor minerals, as could delayed development of suitable processing pathways.

Second, the United States also lacks suitable processing facilities and faces challenges to developing economically viable metallurgical plants. The Chinese steel and nonferrous metals sectors, by contrast, possess ample technical expertise and processing capacity that could be adapted to handle nodules as a feedstock, in addition to vast downstream capacity to process seafloor minerals into battery cathode active materials and stainless steels.

Third, regulatory and political pathways that would allow the U.S. to exploit and access seafloor minerals pose continued uncertainties. The United States is not a party to the UN Convention on the Law of the Sea (UNCLOS) and last year asserted the right to unilaterally issue licenses and permits to U.S. citizens to explore and exploit polymetallic nodules in high seas waters beyond national jurisdiction.² This firmly sets the U.S. apart from procedures to pursue seafloor minerals in international waters through the International Seabed Authority (ISA) established by UNCLOS.

Lastly, U.S. federal seafloor mineral licensing and permitting pathways have no precedent for actual use and require substantial revision and modernization to make them fit for purpose. Meanwhile, seafloor mineral deposits within U.S. sovereign waters remain relatively less characterized and require further assessment for commercial potential. Additionally, opposition to seafloor minerals activities by many environmental and civil society groups remains prevalent and organized.

The seafloor minerals sector may emerge as a new dimension in which the U.S. and China compete to exert geopolitical influence and assert de-facto control over ocean regions and sea

¹ Obayashi, Yuka. "Japan Retrieves Rare Earth Mud from Deep Seabed in Test Mission." Reuters, February 2, 2026. <https://www.reuters.com/science/japan-retrieves-rare-earth-mud-deep-seabed-test-mission-2026-02-02/>

² The White House. "Unleashing America's Offshore Critical Minerals and Resources." April 24, 2025. <https://www.whitehouse.gov/presidential-actions/2025/04/unleashing-americas-offshore-critical-minerals-and-resources/>.

lines of communication. China has already explored or secured bilateral cooperative agreements with small island nations like Kiribati and the Cook Islands to partner on seafloor minerals exploration, strengthening Beijing’s diplomatic ties across the Pacific.³ Meanwhile, China’s international seafloor mineral claims through the International Seabed Authority—and potential mineral recovery operations in the future—establish avenues for persistent Chinese naval and civil maritime presence in those areas.

Such considerations highlight seafloor minerals as a potentially disruptive domain with multiple vectors of strategic significance. Yet the United States government will need to proceed calculatingly to maximize the degree to which mineral exploration and collection can advance this varied set of military, critical minerals, and geopolitical interests. The United States should particularly prioritize mineral resource development in U.S. sovereign waters and partnerships to explore and exploit resources in the exclusive economic zones of other countries. Such partnerships could emphasize technical cooperation, collaborative scientific surveys, coordinated regulatory development, downstream supply chain agreements, and resource area protection.

Meanwhile, federal policies should mobilize domestic scientific resources to accelerate federal regulatory development, intensify seabed mineral resource mapping, study mineral processing approaches, and improve technologies and practices for minimizing exploration and recovery impacts. Congress should consult the U.S. Navy to explore ways to leverage the strong dual-use potential of relevant underwater vehicle and technology capabilities. Finally, Congress should pass legislation to correct key weaknesses of the Deep Seabed Hard Mineral Resources Act and to clarify the status of international seafloor minerals arriving in the U.S. and partner countries for policy program eligibility and trade purposes.

Seafloor Minerals and U.S. Critical Minerals Security

In total, seafloor mineral deposits boast a staggering unknown wealth of critical minerals. The area of seafloor potentially containing prospective polymetallic nodule occurrences is greater than 51 million square kilometers,⁴ exceeding the landmass of the continent of Asia. Meanwhile, one estimate of the total tonnage of ferromanganese crusts in the central Pacific arrived at a figure of 7.53 billion dry metric tons,⁵ exceeding terrestrial reserves of cobalt and yttrium by

³ Paik, Kathryn, and Gracelin Baskaran. Does the U.S.–Cook Islands Seabed Minerals Announcement Signal a New Front in Great Power Competition? August 20, 2025. <https://www.csis.org/analysis/does-us-cook-islands-seabed-minerals-announcement-signal-new-front-great-power-competition>.

⁴ Lusty, Paul A. J., and Bramley J. Murton. “Deep-Ocean Mineral Deposits: Metal Resources and Windows into Earth Processes.” *Elements* 14, no. 5 (2018): 301–306. <https://doi.org/10.2138/gselements.14.5.301>

⁵ Hein, James R., Kira Mizell, Andrea Koschinsky, and Tracey A. Conrad. “Deep-Ocean Mineral Deposits as a Source of Critical Metals for High- and Green-Technology Applications: Comparison with Land-

three to four-fold. However, such calculations remain extraordinarily uncertain for all seabed mineral types. In general most seabed mineral resources reside in international waters, with one research review suggesting that 81% of polymetallic nodules,⁶ 58% of seafloor massive sulfides, and 46% of ferromanganese crusts occur outside any individual nation’s sovereign waters.

The magnitude of these resources could pose significant implications for global mineral markets. The best-characterized seafloor mineral resource region and the largest polymetallic nodule field in the world, the Clarion-Clipperton Fracture Zone (CCZ), may contain a total of 6 billion metric tons of manganese, 270 million metric tons of nickel, 230 million metric tons of copper, and 50 million metric tons of cobalt. This alone exceeds known terrestrial cobalt and manganese resources by twofold and nearly matches known nickel resources on land.

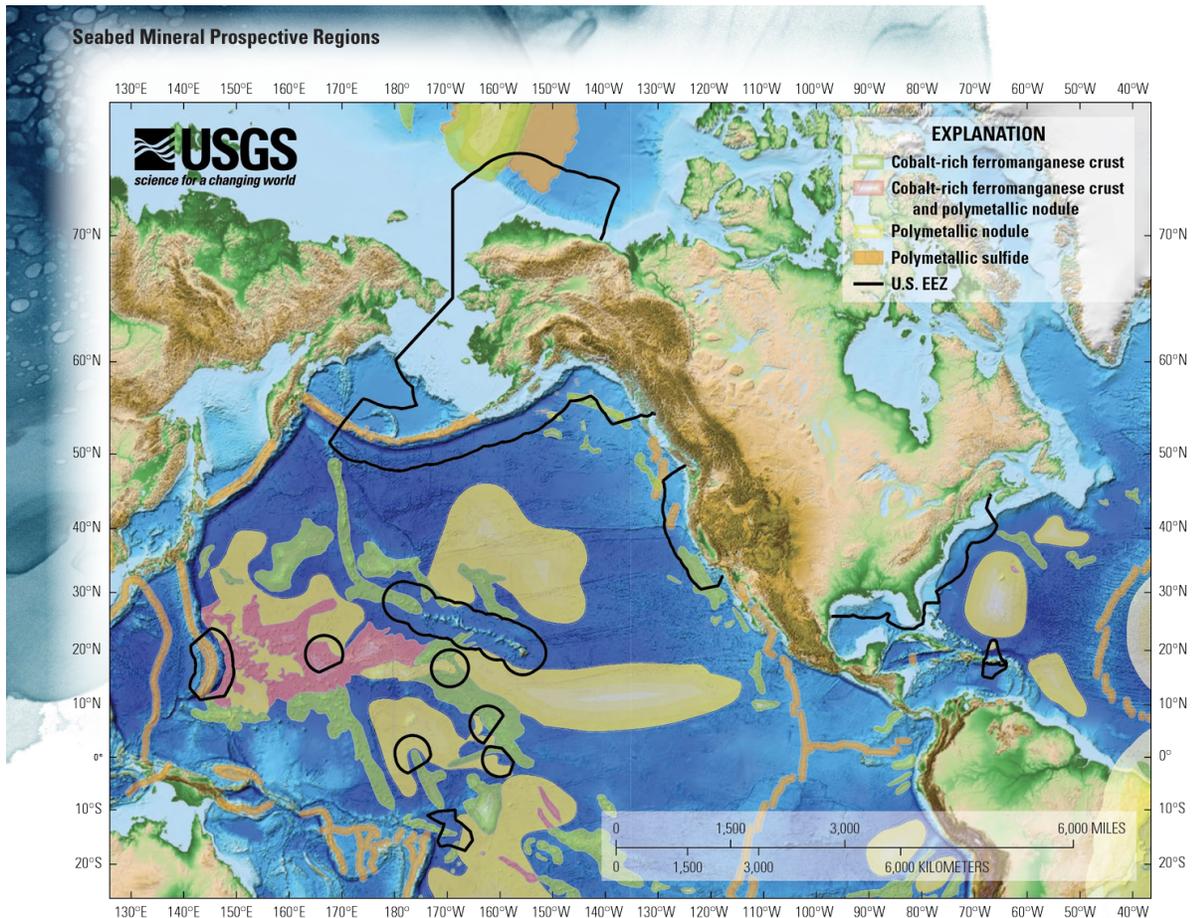
Table 1: Comparison of seafloor polymetallic nodule and land-based resources for relevant metals of interest contained within nodule materials.

(millions of metric tons)	Cobalt	Nickel	Manganese	Copper
Estimated tonnage in Clarion-Clipperton Zone nodules	50	270	6000	230
Current estimated terrestrial reserves	8.3	100	1700	890
Current estimated terrestrial resources	25	300	>1700	3500

Based Resources.” Ore Geology Reviews 51 (June 2013): 1–14.
<https://doi.org/10.1016/j.oregeorev.2012.12.001>.

⁶ Petersen, S., A. Krättschell, N. Augustin, J. Jamieson, J. R. Hein, and M. D. Hannington. “News from the Seabed – Geological Characteristics and Resource Potential of Deep-Sea Mineral Resources.” Marine Policy 70 (August 2016): 175–87. <https://doi.org/10.1016/j.marpol.2016.03.012>.

Figure 1: Map of global seabed mineral prospective regions, reproduced from the U.S. Geological Survey Global Seabed Mineral Resources, 2025. Original caption: “Global seabed mineral prospective regions, including those that occur within the U.S. Exclusive Economic Zone (U.S. EEZ). More information on these regions can be found in Mizell and others (2022) and Gartman and others (2022).”



Many countries including the United States possess prospective seafloor mineral occurrences within their sovereign waters. Potential resources within the U.S. Exclusive Economic Zone (U.S. EEZ) remain insufficiently characterized. They primarily include ferromanganese crusts and seafloor massive sulfides off the U.S. West Coast and Alaska, as well as various resource types including nodules within the EEZ regions of Hawaii, Guam, the Northern Mariana Islands, American Samoa, and the United States Minor Outlying Islands in the central Pacific.⁷ As of this

⁷ U. S. Geological Survey. *U.S. Geological Survey Global Seabed Mineral Resources*. Nos. 2025–3017. U.S. Geological Survey, 2025. <https://doi.org/10.3133/fs20253017>.

February, the National Oceanic and Atmospheric Administration (NOAA) has commenced a new survey project to map seafloor minerals in federal waters off American Samoa.⁸

Pilot-scale technologies or vehicles for collecting ferromanganese crusts or seafloor massive sulfides remain fairly underdeveloped. The resource potential of such mineral occurrences also remains poorly characterized, making ferromanganese crusts and seafloor massive sulfides relatively irrelevant for concretely advancing U.S. mineral security interests within the next several years.

In contrast, promising privately-led expeditions within recent years have demonstrated full seabed-to-ship collector systems for polymetallic nodules, giving commercial-scale nodule recovery a considerably higher near-term level of technological readiness. Prospective operators have conducted much more detailed surveys and economic assessments of nodule fields in the CCZ and in the sovereign waters of the Cook Islands.

To understand the potential economic and strategic significance of nodule recovery, consider that a sizable fleet of 10 production ships each collecting 3 million metric tons of dry nodules per year would produce 7,668,000 tons of manganese, 370,000 tons of nickel, 297,000 tons of copper, and 51,000 tons of cobalt annually after processing losses.⁹ This would exceed one-third of total global manganese mine production in 2025, and amounts to nearly one-tenth of global nickel mining in 2025.¹⁰ This annual manganese and nickel output would exceed U.S. nationwide consumption by over 10x and 1.6x, respectively, while the copper production would be equivalent to about 16.5% of U.S. copper consumption in 2024.¹¹ Meanwhile, this quantity of cobalt equates to over 5x current national consumption and would likely suffice to supply batteries for nationwide future U.S. battery annual demand (up to 52,000 tons of cobalt each year by 2050).¹²

This exercise illustrates that even a single production vessel could in theory deliver total U.S. manganese independence, and supply half of current U.S. cobalt needs and around 17% of current U.S. nickel needs. In short, polymetallic nodules carry considerable potential significance

⁸ “NOAA to Map Critical Mineral Deposits in Deep Waters off American Samoa | National Oceanic and Atmospheric Administration.” January 22, 2026. <https://www.noaa.gov/news-release/noaa-to-map-critical-mineral-deposits-in-deep-waters-off-american-samoa>.

⁹ Massachusetts Institute of Technology. *Report to the International Seabed Authority on the Development of an Economic Model and System of Payments for the Exploitation of Polymetallic Nodules in the Area*. June 3, 2022. PDF file. <https://isa.org.jm/wp-content/uploads/2022/12/paysysmodel-3jun.pdf>.

¹⁰ U. S. Geological Survey. *Mineral Commodity Summaries 2026*. No. 2026. U.S. Geological Survey, 2026. <https://doi.org/10.3133/mcs2026>.

¹¹ The Breakthrough Institute. “Taking Inventory of Critical Mineral Stockpiling.” Accessed February 17, 2026. <https://thebreakthrough.org/issues/energy/taking-inventory-of-critical-mineral-stockpiling>.

¹² The Breakthrough Institute. “Metals for the Future.” Accessed February 17, 2026. <https://thebreakthrough.org/issues/energy/metals-for-the-future>.

for U.S. manganese, nickel, and cobalt strategy. If processing operations produce battery-grade nickel and cobalt compounds suitable for high-performance battery cathode active materials, then nodules could play a key role in securing supply chains for a more competitive U.S. lithium-ion battery manufacturing sector. Nodules would still contribute helpfully to U.S. copper production, but pose less significant national copper supply implications.

However, the United States currently lacks domestic capabilities for processing polymetallic nodules. China dominates conventional smelting using nickel laterite ore feedstocks, especially the energy-intensive rotary kiln electric furnace pathway which some nodule operators have proposed as their initial processing approach.^{13,14} China also controls over 75% of nickel-manganese-cobalt battery cathode active material production.¹⁵ If the U.S. or partner countries do not develop processing facilities compatible with nodules as feedstock, then nodules recovered by American or allied production vessels might nevertheless require export to China or Chinese-owned smelters in Indonesia for downstream processing.

As for rare earth elements, most companies pursuing seafloor nodules and reports from independent consultants, including firms contracted by the ISA, do not currently highlight or even mention rare earths in their life cycle assessments or economic analyses.^{16,17,18,19,20} This pattern suggests that the sector generally does not consider rare earth element separation from nodule feedstocks to be economic at this time. Co-production of uncertain trace quantities of rare earths in nodules would require extensive additional onshore processing steps and plant equipment that may be cost prohibitive and add considerable project risk. Nevertheless, a few

¹³ Trytten, Lyle. "Nickel Industry – Part 2 – Processing Nickel Laterites and Smelting." Nickel Institute, August 7, 2024.

<https://nickelinstitute.org/en/blog/2024/august/nickel-industry-part-2-processing-nickel-laterites-and-smelting/>

¹⁴ Benchmark Mineral Intelligence. *TMC NORI-D – Life Cycle Assessment for Polymetallic Nodule Project and Comparison to Key Land-Based Routes*. Prepared for The Metals Company, March 2023. PDF file.

https://metals.co/wp-content/uploads/2023/03/TMC_NORI-D_LCA_Final_Report_March2023.pdf

¹⁵ International Energy Agency. *Global EV Outlook 2024*. Paris: International Energy Agency, April 23, 2024. <https://www.iea.org/reports/global-ev-outlook-2024>

¹⁶ Benchmark Mineral Intelligence. *TMC NORI-D – Life Cycle Assessment for Polymetallic Nodule Project and Comparison to Key Land-Based Routes*. Prepared for The Metals Company, March 2023. PDF file.

https://metals.co/wp-content/uploads/2023/03/TMC_NORI-D_LCA_Final_Report_March2023.pdf

¹⁷ "TMC Releases Two Economic Studies with Combined NPV of \$23.6B and Declares World-First Nodule Reserves | The Metals Company." Accessed February 17, 2026. <https://investors.metals.co/news-releases/news-release-details/tmc-releases-two-economic-studies-combined-npv-236b-and-declares/>.

¹⁸ CRU Consulting. *Polymetallic Nodule Valuation: A Report for the International Seabed Authority*.

Prepared for the International Seabed Authority, 24 August 2020. PDF file. https://www.isa.org.jm/wp-content/uploads/2022/12/CRU_ISA-Polymetallic-nodule-valuation-report_24Aug2020.pdf

¹⁹ Massachusetts Institute of Technology. *Report to the International Seabed Authority on the Development of an Economic Model and System of Payments for the Exploitation of Polymetallic Nodules in the Area*. June 3, 2022. PDF file. <https://isa.org.jm/wp-content/uploads/2022/12/paysysmodel-3jun.pdf>

²⁰ Van Nijen, Kris, Steven Van Passel, and Dale Squires. "A Stochastic Techno-Economic Assessment of Seabed Mining of Polymetallic Nodules in the Clarion Clipperton Fracture Zone." *Marine Policy* 95 (September 2018): 133–41. <https://doi.org/10.1016/j.marpol.2018.02.027>.

cooperative agreements between prospective nodule operators and firms with metallurgical processing and refining expertise do hint at continued efforts to evaluate rare earth production from nodules.^{21,22}

The very recent Japanese expedition to test a collection system for deep sea rare earth muds does highlight another potential avenue for rare earths production from seafloor minerals. Preliminary assessments of mud composition suggest that such resources could offer total grades and heavy rare earth enrichment similar to the ionic adsorption clay deposits predominant in China (500-2,000 ppm and 50-200 ppm, respectively).²³ Occasional samples have even exhibited concentrations reaching the low end of hard rock deposits like carbonatite formations (~8,000 ppm).²⁴ However, mapping and characterization of rare earth muds remains many years if not decades behind nodule field assessments. Additionally, even Japan is unlikely to imminently exploit rare earth muds. One consideration is that the expedition vessel *Chikyu* is specialized for deep sea scientific drilling and must balance competing missions, with commercial-scale recovery likely requiring a different dedicated production vessel. Rare earth muds are also another unconventional feedstock without developed processing flowsheets, although Japanese industry and scientists do possess meaningful expertise in rare earth processing, having long partnered with the Australian mining firm Lynas to establish a non-Chinese rare earth processing supply chain.²⁵

Overall, seabed minerals could significantly bolster U.S. critical minerals security, but onshore processing capabilities and facilities remain a crucial gap that the sector would have to fill before being able to realize that potential.

²¹ Metals, Impossible. “ReElement Technologies Corporation and Impossible Metals Announce Collaboration on First U.S. Deep Sea Nodule Refinement Program.” Impossible Metals, July 21, 2025. <https://impossiblemetals.com/blog/reelement-technologies-corporation-and-impossible-metals-announce-collaboration-on-first-u-s-deep-sea-nodule-refinement-program/>.

²² Metals, Impossible. “Aqua Metals and Impossible Metals Sign MOU to Advance Sustainable U.S. Critical Minerals Supply Chain.” Impossible Metals, September 16, 2025. <https://impossiblemetals.com/blog/aqua-metals-and-impossible-metals-sign-mou-to-advance-sustainable-u-s-critical-minerals-supply-chain/>.

²³ Kato, Yasuhiro, Koichiro Fujinaga, Kentaro Nakamura, et al. “Deep-Sea Mud in the Pacific Ocean as a Potential Resource for Rare-Earth Elements.” *Nature Geoscience* 4, no. 8 (2011): 535–39. <https://doi.org/10.1038/ngeo1185>.

²⁴ Takaya, Yutaro, Kazutaka Yasukawa, Takehiro Kawasaki, Koichiro Fujinaga, Junichiro Ohta, Yoichi Usui, Kentaro Nakamura, Jun-Ichi Kimura, Qing Chang, Morihisa Hamada, Gjergj Dodbiba, Tatsuo Nozaki, Koichi Iijima, Tomohiro Morisawa, Takuma Kuwahara, Yasuyuki Ishida, Takao Ichimura, Masaki Kitazume, Toyohisa Fujita, and Yasuhiro Kato. “The Tremendous Potential of Deep-Sea Mud as a Source of Rare-Earth Elements.” *Scientific Reports* 8 (2018): 5763. <https://www.nature.com/articles/s41598-018-23948-5.pdf>

²⁵ Davis, River Akira, and Kiuko Notoya. “How Japan Built a Rare-Earth Supply Chain Without China.” *The New York Times*, December 8, 2025. <https://www.nytimes.com/2025/12/08/business/japan-rare-earths-lynas.html>

The Seafloor Minerals Technology Race

The development of seabed mineral collector vehicles and recovery systems remains robustly competitive, with some observers judging Chinese robotic platforms in this sector as lagging behind Western platforms by several years.²⁶ However, such a lead is not to be taken for granted. Chinese seafloor mineral exploration efforts are moving forward via powerful partnerships among Chinese universities, research institutions, and large state-owned corporations with extensive terrestrial mining and metallurgical expertise. Any academic oceanographer can attest that Chinese universities have invested impressive effort and resources into the oceanographic sciences,²⁷ expanding research departments considerably and notably building a research vessel fleet that now exceeds 64 ships.²⁸

But in terms of reported capabilities and operational testing, Chinese nodule exploration missions have not yet passed milestones achieved by North American and European firms several years ago. Global Sea Mineral Resources NV (GSR), a company operating in Belgium's exploration zone in the CCZ, harvested a combined 1,100 metric tons of nodules in 2021 using a 35-ton vehicle pre-prototype at depths exceeding 4,500 meters.²⁹ GSR also demonstrated a remarkable recovery of the collector vehicle from the seafloor at 4,500 meters depth after the umbilical connection to the surface support vessel broke. In November 2022, The Metals Company successfully recovered 3,000 metric tons of nodules from a depth of around 4,300 meters.³⁰ In comparison, Chinese vehicle testing only breached the 4,100-meter depth mark in mid-2024, with missions having yet to collect more than a few tons of nodules.³¹

²⁶ Bottolier-Depois, Amelie, and Mary Yang. "China Carefully Assembling a Deep-Sea Mining Strategy." Phys.org, June 10, 2025. <https://phys.org/news/2025-06-china-deep-sea-strategy.html>

²⁷ UCIGCC. "Oceans of Ambition: The Rise of China's Blue Science - IGCC." Accessed February 17, 2026. <https://ucigcc.org/blog/oceans-of-ambition-the-rise-of-chinas-blue-science/>.

²⁸ CSIS. "Surveying the Seas: China's Dual-Use Research Operations in the Indian Ocean." Accessed February 17, 2026. <https://features.csis.org/hiddenreach/china-indian-ocean-research-vessels>.

²⁹ Peacock, Thomas. *The GSR Patania II Expedition: Technical Achievements & Scientific Learnings*. Report for Global Sea Mineral Resources, 11 March 2023. PDF file. https://deme-gsr.com/wp-content/uploads/2023/03/2023_March11_GSR_PataniaII_Final_sp_2-page-version-compressed-2.pdf

³⁰ The Metals Company. "NORI and Allseas Lift Over 3,000 Tonnes of Polymetallic Nodules to Surface from Planet's Largest Deposit of Battery Metals, as Leading Scientists and Marine Experts Continue Gathering Environmental Data | The Metals Company." Accessed February 17, 2026. <https://investors.metals.co/news-releases/news-release-details/nori-and-allseas-lift-over-3000-tonnes-polymetallic-nodules/>.

³¹ Xinhua News Agency. "China's Deep-Sea Heavy-Duty Mining Vehicle Reaches Record Depth in Sea Trial." Xinhua, July 9, 2024. <https://www.news.cn/tech/20240709/34ee304d078241e7967d954cd8857de9/c.html>

On the other hand, China Minmetals Corporation has received both ISA³² and Chinese government approvals³³ to imminently test a 40-ton vehicle, aiming to assess collection of 1,300 tons of nodules in one of the Chinese-held CCZ exploration areas at depths potentially exceeding 5,000 meters.³⁴ This proposed mission clearly signals the level of Chinese ambition to catch up with demonstrated overseas capabilities, and if successful, will arguably signal imminent technological parity. A Chinese mission in mid-2024 also demonstrated its prototype vehicle “Kaituo-2” (开拓二号) to be capable of pilot excavation harvesting up to ~200 kilograms of ferromanganese crusts at 4,100 meters.³⁵ While the scale of this test was small, other international ventures have not pursued technologies to target crust deposits as actively.

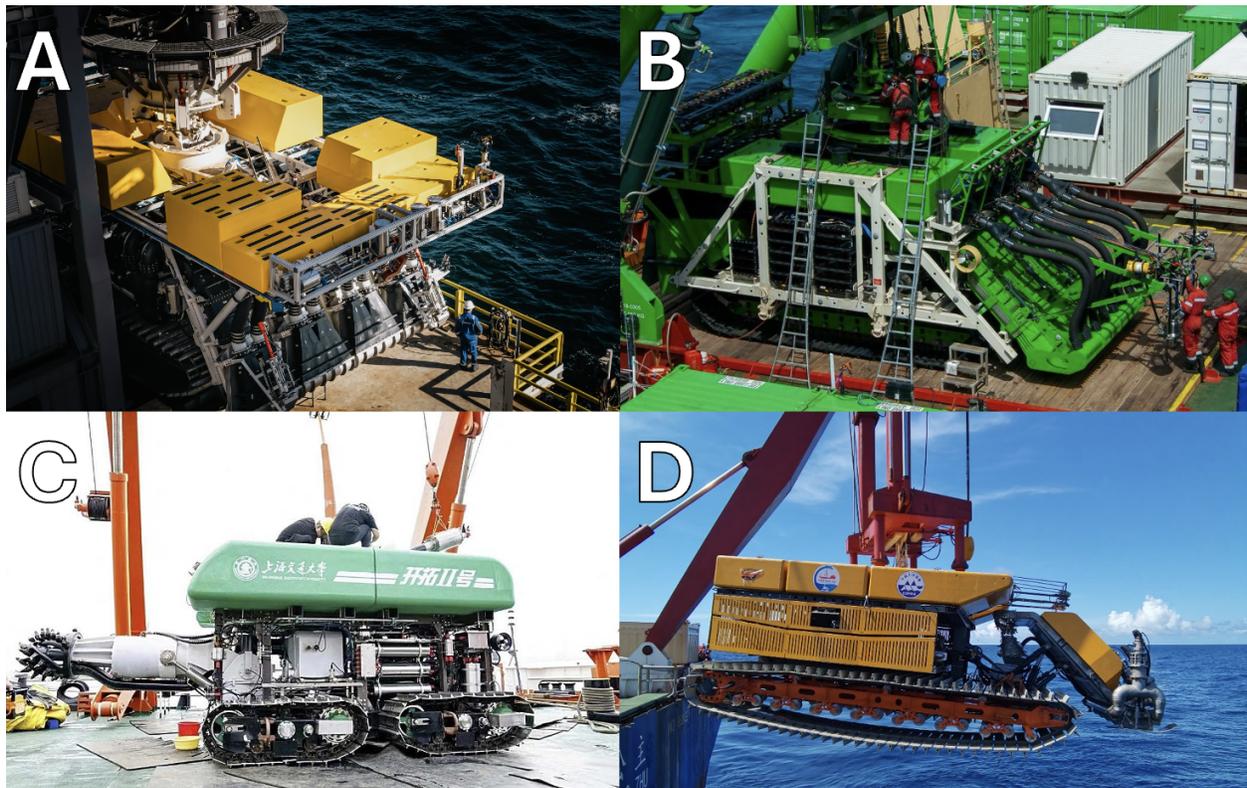
³² Barron's. “UN Body Clears China's Minmetals for Deep-Sea Mining Testing.” Barron's, May 20, 2025. <https://www.barrons.com/news/un-body-clears-china-s-minmetals-for-deep-sea-mining-testing-106b03aa>

³³ Minmetals. “China Approves First Environmental Impact Statement for Deep-Sea Mining Vehicle Tests.” Accessed February 17, 2026. http://www.minmetals.com/english/news/minmetalsnews/202506/t20250604_309018.html.

³⁴ China Minmetals Group Co., Ltd. Environmental Impact Statement and Corporate Overview. April 2024. PDF file. <https://www.minmetals.com.cn/xxgk/qygg/202404/P020240407410576337793.pdf>

³⁵ Xinhua News Agency. “China's Deep-Sea Heavy-Duty Mining Vehicle Reaches Record Depth in Sea Trial.” Xinhua, July 9, 2024. <https://www.news.cn/tech/20240709/34ee304d078241e7967d954cd8857de9/c.html>

Figure 2: a) Pilot collector vehicle tested by The Metals Company and Allseas. b) *Patania II* pre-prototype collector seabed nodule collector vehicle tested by Global Sea Mineral Resources NV. c) Kaituo-2 prototype nodule and crust collector vehicle tested by Shanghai Jiao Tong University. d) Prototype collector vehicle tested by China Minmetals Corporation, the immediate predecessor to a 40-ton prototype vehicle awaiting testing by China Minmetals.



On the scientific front, the United States maintains a strong position within the oceanographic and ocean engineering disciplines, but China's research institutions and research community have grown considerably over the past 15 years and are now arguably also at the global cutting edge. The exploration and recovery of seafloor minerals requires extensive environmental monitoring and science-informed operational planning, making ocean sciences a crucial set of capabilities for driving progress in this sector.

In October and November of 2025, competing expeditions within weeks of one another by China and the United States to map the EEZ waters of the Cook Islands presented some contrasts between the scale of the two different surveys. The NOAA-sponsored American mission aboard the *E/V Nautilus* performed a three-week voyage employing multiple deep-sea remotely operated

vehicles (ROVs)³⁶ and a towed sled, deploying two seafloor mini-landers, and mapping over 14,000 square kilometers of seafloor.³⁷ The U.S. cruise included a considerable focus on cataloguing seafloor wildlife and flora, broadcasting many of its activities live to the public and subsequently making basic oceanographic data available online.

Weeks later, the Chinese vessel *Da Yang Yi Hao* (大洋一号) conducted an expedition just three days long, conducting mapping, marine gravimetric measurements, deep camera tows, and sediment sampling.^{38,39} However, this expedition represents just the start of China's prominent five-year agreement with the Cook Islands to assist in mapping the nation's seafloor mineral resources, and Chinese partners may step up the scope and scale of such expeditions moving forward.

This episode nevertheless illustrates one route with which the United States could compete by negotiating credible partnerships with countries seeking to assess their sovereign seabed resources. Leveraging considerable strengths in oceanographic science and technologies, coupled with balanced, transparent efforts to perform ecological assessments and advance marine conservation while assessing economic potential, the United States can make very attractive offers to countries interested in both conducting more holistic, public-facing scientific studies, and in counterbalancing growing Chinese diplomatic and economic outreach to the region.

Apart from such physical, biological, and chemical oceanographic analyses, engineering priorities for further development include surveys of unmapped regions; progress towards reliable year-round operation of collection systems; capabilities for rapidly restoring operation following system failure; robotic systems for decentralized, distributed nodule recovery as an alternative to collector-and-riser-pipe systems; and onshore processing capabilities and facilities.

³⁶ "NOAA-Led Ocean Mapping Expedition in Cook Islands Hailed as a Resounding Success | National Oceanic and Atmospheric Administration." November 20, 2025. <https://www.noaa.gov/news-release/noaa-led-ocean-mapping-expedition-in-cook-islands-hailed-as-resounding-success>.

³⁷ Ocean Exploration Trust and NOAA Ocean Exploration. *NA176 Expedition Summary: Deep-Sea Habitats of the Cook Islands Exclusive Economic Zone (October 1–21, 2025)*. PDF, November 2025. <https://nautiluslive.org/sites/default/files/documents/2025-11/NA176%20Expedition%20Summary%20%283%29.pdf>

³⁸ *R/V Da Yang Hao's Acoustic Laboratory with Dr John Parianos of the Seabed Minerals Authority and Professor Li, Chief Scientist on Board. Helping Scientists Understand Seafloor Structures, Marine Habitats, and the Geology of Our Deep Ocean.* Cook Islands Seabed Minerals Authority. n.d. Accessed February 17, 2026. <https://www.facebook.com/reel/1509419936775842/>.

³⁹ Grady, John. "Chinese Research Vessel Arrives in Cook Islands for Seabed Surveys." *The Maritime Executive*, November 10, 2025. <https://maritime-executive.com/article/chinese-research-vessel-arrives-in-cook-islands-for-seabed-surveys>

Contrasts Between Terrestrial Mining and Seafloor Mineral Recovery

Economic implications

Most prospective companies seeking to collect polymetallic nodules claim that their commercial-scale operations will compete very favorably with current terrestrial nickel and cobalt mine production. Global Sea Mineral Resources NV published a 2022 study estimating that thanks to byproduct recovery of cobalt, manganese, and copper, polymetallic nodules would rank competitively at the lowest-cost extremes of global nickel mine production based on 2016 production cost curves.⁴⁰ In more recent economic pre-feasibility studies published in 2025, The Metals Company similarly asserted that cobalt, manganese, and nickel byproducts would enable them to achieve low production costs in the first quartile of the global nickel cost curve.⁴¹ Even assuming these industry estimates are biased towards optimism, they suggest a good theoretical basis for the economic competitiveness of nodule collection relative to conventional mining.

At the same time, a few remaining uncertainties may considerably impact the economic viability of polymetallic nodule collection in practice, posing concerns that will require more extensive testing or operational experience to fully address. Commercial-scale collector vehicles, riser pipe systems, production vessels, and onshore processing facilities will require specialized development with considerable upfront capital expenditures that may exceed current projections. Setbacks like operational outages or loss of equipment at sea carry the potential to escalate costs while reducing realized production, making the economics of nodule collection highly sensitive to reliable operation.⁴²

Assuming that steady technological advances eventually enable collector systems to work reliably, however, polymetallic nodules do boast a number of intrinsic economic advantages. First, the presence of multiple valuable metals at relatively high concentrations within nodule materials compares very favorably to terrestrial deposits. For instance, with around 1.4% nickel and 1.2% copper content, sampled CCZ nodules are comparable to the typical ore grade of

⁴⁰ Van Nijen, Kris, Steven Van Passel, and Dale Squires. "A Stochastic Techno-Economic Assessment of Seabed Mining of Polymetallic Nodules in the Clarion Clipperton Fracture Zone." *Marine Policy* 95 (September 2018): 133–41. <https://doi.org/10.1016/j.marpol.2018.02.027>.

⁴¹ The Metals Company. "TMC Releases Two Economic Studies with Combined NPV of \$23.6B and Declares World-First Nodule Reserves | The Metals Company." Accessed February 18, 2026. <https://investors.metals.co/news-releases/news-release-details/tmc-releases-two-economic-studies-combined-npv-236b-and-declares/>.

⁴² Wang, Chang, Siyuan Zhou, Xiaojie Shu, and Huiling Song. "Deep-Sea Mining: A Potential Solution to Secure Critical Energy Minerals Availability." *Npj Ocean Sustainability* 4, no. 1 (2025): 59. <https://doi.org/10.1038/s44183-025-00162-1>.

Indonesian nickel saprolites (1.3%) and hydrometallurgical plant feed material (1.1%),⁴³ and would exceed the ore grade of 7 of the 10 largest operating copper mines in the world today.⁴⁴ Nodule operations enjoy more streamlined ship-based infrastructure that can be reused across successive sites, in contrast to terrestrial mines that must build dedicated onsite facilities for each deposit—from transportation infrastructure like roads and airstrips, to power grid interconnections, to mill facilities and the engineering plan of the mine itself. Nodule collection also requires a relatively minimal project development phase in contrast to surface or underground mines that require extensive excavation before ever mining their first unit of ore.

Environmental and human impacts

In all likelihood, the direct air pollution and greenhouse gas emissions from polymetallic nodule recovery operations will offer notable improvements relative to terrestrial mining. Air quality and emission impacts are limited to the production vessel and any supporting ships, in comparison to pollution effects from dust clouds; the sizable fleet of typically diesel-fueled haul trucks, excavators, and specialized vehicles in operation at a conventional mine; and onsite milling, processing, pumping, and ventilation equipment that may require power from onsite diesel generators at remote sites. In addition, a single production vessel collecting 3 million tons of dry nodules per year will harvest the equivalent manganese, nickel, copper, and cobalt output of several terrestrial mines. Seafloor mineral operations are furthermore located at considerable distances away from the nearest human settlements, potentially by hundreds or thousands of kilometers.

Processing and smelting of ores, however, typically produces far greater emissions and air and water pollution impacts than the mining stage.⁴⁵ The total environmental and public health implications of seafloor nodule collection consequently depend heavily on the approaches used to process the nodules on shore. Preliminary life-cycle analyses conducted by researchers in partnership with prospective polymetallic nodule operators suggest that nodule recovery and processing result in less terrestrial acidification, freshwater pollution, marine water pollution, water consumption, and greenhouse gas emissions than conventional mining and processing of

⁴³ Taufiq Hidayat et al. *Recent Growth of Nickel Laterite Processing in Indonesia* (Metallurgical Engineering Research Group, Institut Teknologi Bandung, June 2024), <https://d3e2i5nuh73s15.cloudfront.net/wp-content/uploads/2024/06/01.02-RECENT-GROWTH-OF-NICKEL-LATERITE-PROCESSING-IN-INDONESIA.pdf>.

⁴⁴ Baskaran, Gracelin, and Meredith Schwartz. *Rethinking Copper Tariffs*. July 23, 2025. <https://www.csis.org/analysis/rethinking-copper-tariffs>.

⁴⁵ Istrate, Robert, Aina Mas-Fons, Antoine Beylot, et al. “Decarbonizing Lithium-Ion Battery Primary Raw Materials Supply Chain.” *Joule* 8, no. 11 (2024): 2992–3016. <https://doi.org/10.1016/j.joule.2024.10.003>.

the same metals.^{46,47} However, onshore processing impacts may vary widely between different companies depending on selected metallurgical process flowsheets. For instance, the existing rotary kiln electric furnace pathway for processing nickel laterite ores in Indonesia using coal-fired energy can result in a high carbon intensity of >90 tons of CO₂ per ton of nickel metal.⁴⁸ On the other hand, alternative flowsheets considered for nodule processing such as variants of the Cuprion process (a reductive ammonia-ammonium carbonate leach) may avoid energy-intensive high-temperature processing requirements.^{49,50,51}

In ecological terms, terrestrial mining typically requires full clear-cutting of vegetation in operational areas, while seafloor nodule collection is expected to disturb the upper 5-15 centimeters (2-6 inches) of seafloor sediment.⁵² Nodule collector vehicles will likely kill, injure, or displace most seafloor organisms living on nodule surfaces and on or just below the affected seabed surface. Sediment ejected during collector vehicle operation will produce a suspended cloud of discharged particles near the seafloor, potentially burying, irritating, or obstructing seabed organisms and activities like feeding. Meanwhile, the production vessel will lift deep ocean water along with nodules to the surface and must return this abyssal water back to the ocean, with many proposed systems envisioning release of return water at depths ranging from several kilometers below the surface to just above the seafloor.⁵³ Return water may contain some quantities of sediment, potentially resulting in another plume of particles above the seafloor.

⁴⁶ Benchmark Mineral Intelligence. *TMC NORI-D – Life Cycle Assessment for Polymetallic Nodule Project and Comparison to Key Land-Based Routes*. Prepared for The Metals Company, March 2023. PDF file. https://metals.co/wp-content/uploads/2023/03/TMC_NORI-D_LCA_Final_Report_March2023.pdf.

⁴⁷ Alvarenga, R. A. F., N. Pr eat, C. Duhayon, and J. Dewulf. "Prospective Life Cycle Assessment of Metal Commodities Obtained from Deep-Sea Polymetallic Nodules." *Journal of Cleaner Production* 330 (January 2022): 129884. <https://doi.org/10.1016/j.jclepro.2021.129884>.

⁴⁸ WRI Indonesia. "Nickel Industry Decarbonization Roadmap." (Bahasa Indonesia). June 2025. <https://wri-indonesia.org/en/news/ministry-national-development-planning-ppnbappenas-and-wri-indonesia-ensure-integration-nickel>

⁴⁹ David Dreisinger, "Hydrometallurgical Processing of Polymetallic Nodules from the Clarion Clipperton Zone (CCZ)," UK Seabed Resources Ltd, September 3, 2018, <https://www.isa.org.jm/wp-content/uploads/2022/12/UKSR-1.pdf>

⁵⁰ Niels Verbaan, "Onshore Processing of Nodules: A Review of Metallurgical Flowsheets and Active Testwork Updates," SlideShare, May 5, 2022, <https://www.slideshare.net/iQHub/onshore-processing-of-nodules-a-review-of-metallurgical-flowsheets-and-active-testwork-updates>.

⁵¹ Simon Boel. "Metallurgical Model Presentation: Maximizing Metallurgical Yields at Minimal Environmental Cost." GSR NV. Presentation at Processing Technologies, Metal Recoveries & Economic Feasibility of Deep Sea Mining. Ministry of Environment, Warsaw, Poland (2022). <https://isa.org.jm/wp-content/uploads/2022/12/GSR-2.pdf>

⁵² Seaver Wang, "No, Collecting Seafloor Metals Won't Wreck the Ocean Carbon Cycle," Breakthrough Institute, July 9, 2024, <https://thebreakthrough.org/issues/energy/no-collecting-seafloor-metals-wont-wreck-the-ocean-carbon-cycle>.

⁵³ Cuyvers, Luc, Whitney Berry, Kristina M. Gjerde, Torsten Thiele, and Caroline Wilhelm. *Deep Seabed Mining*. Gland, Switzerland: International Union for Conservation of Nature (IUCN), 2018. <https://portals.iucn.org/library/sites/library/files/documents/2018-029-En.pdf>

However, the abyssal seafloor features exponentially lower biomass than coastal or terrestrial environments, containing around 0.05% organic carbon by dry weight compared to coastal mangrove sediments (5%) and surface soils on land (between 1% and 5%).^{54,55} With increasing depth, zooplankton biomass in the water column decreases exponentially, as does bacterial biomass in the upper 15 centimeters of the seafloor.^{56,57} Scientific surveys emphasize that abyssal seafloor life is surprisingly diverse in terms of the number of observed species,⁵⁸ but in absolute quantitative terms this ecosystem is extremely sparse in living matter with low overall biological productivity, heavily limited by low energy availability.⁵⁹ Additionally, preliminary pilot testing suggests a possibility that seafloor sediment plumes may not travel far from the collector vehicle track and may start settling back down to the seafloor within hours.⁶⁰

⁵⁴ ISA Fact-Check 204/1 – The Carbon Cycle in the Area - International Seabed Authority. July 15, 2024. <https://isa.org/jm/isa-fact-check-2024-1/>.

⁵⁵ Buringh, P. "Organic Carbon in Soils of the World." In *The Role of Terrestrial Vegetation in the Global Carbon Cycle: Measurement by Remote Sensing*, edited by G. M. Woodwell, 91–109. Chichester, England: John Wiley & Sons Ltd., 1984. https://scope.dge.carnegiescience.edu/SCOPE_23/SCOPE_23_3.1_chapter3_91-109.pdf

⁵⁶ Wei, Chih-Lin, Gilbert T. Rowe, Elva Escobar-Briones, et al. "Global Patterns and Predictions of Seafloor Biomass Using Random Forests." *PLOS ONE* 5, no. 12 (2010): e15323. <https://doi.org/10.1371/journal.pone.0015323>.

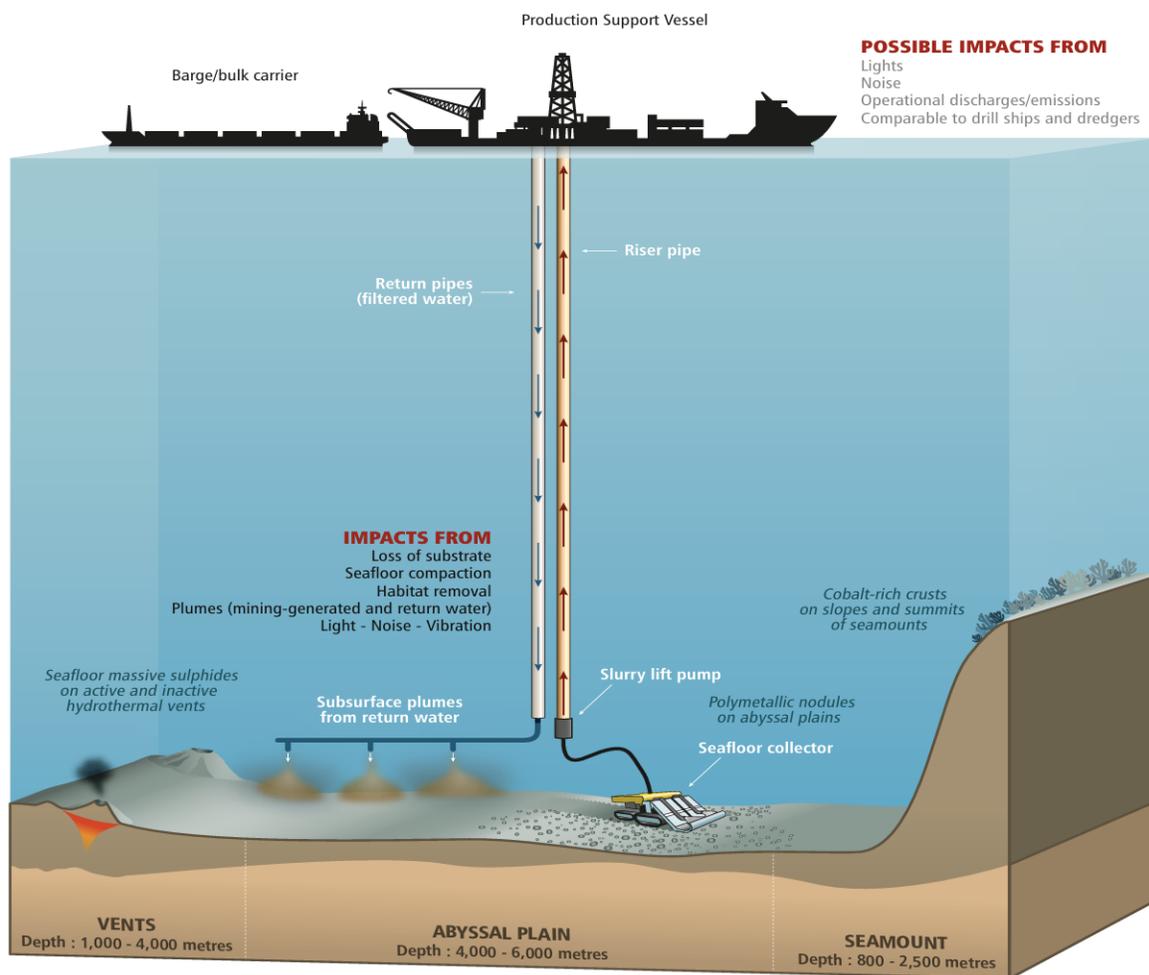
⁵⁷ Jørgensen, Bo Barker, and Antje Boetius. "Feast and Famine — Microbial Life in the Deep-Sea Bed." *Nature Reviews Microbiology* 5, no. 10 (2007): 770–81. <https://doi.org/10.1038/nrmicro1745>.

⁵⁸ Jones, Daniel O. B., Maria Belen Arias, Loïc Van Audenhaege, et al. "Long-Term Impact and Biological Recovery in a Deep-Sea Mining Track." *Nature* 642, no. 8066 (2025): 112–18. <https://doi.org/10.1038/s41586-025-08921-3>.

⁵⁹ Jørgensen, Bo Barker, and Antje Boetius. "Feast and Famine — Microbial Life in the Deep-Sea Bed." *Nature Reviews Microbiology* 5, no. 10 (2007): 770–81. <https://doi.org/10.1038/nrmicro1745>.

⁶⁰ Muñoz-Royo, Carlos, Raphael Ouillon, Souha El Mousadik, Matthew H. Alford, and Thomas Peacock. "An in Situ Study of Abyssal Turbidity-Current Sediment Plumes Generated by a Deep Seabed Polymetallic Nodule Mining Preprototype Collector Vehicle." *Science Advances* 8, no. 38 (2022): eabn1219. <https://doi.org/10.1126/sciadv.abn1219>.

Figure 3: Conceptual diagram illustrating potential marine environmental impacts associated with seafloor polymetallic nodule recovery. Graphic originally published in Cuyvers et al., 2018.⁶¹



Other clear impact categories include light pollution from seafloor collector vehicles, as well as potentially significant underwater noise caused by pumping systems, the rush of water and nodules traveling upwards to the production vessel, and other vessel and system operations. However, best practices utilized in other maritime sectors like offshore wind farm and offshore oil and gas development can help improve noise mitigation.^{62,63}

⁶¹ Cuyvers, Luc, et al. "Deep Seabed Mining, a Rising Environmental Challenge." Gland, Switzerland: IUCN, 2018. <https://portals.iucn.org/library/sites/library/files/documents/2018-029-En.pdf>.

⁶² Mooney, T. A., M. H. Andersson, and J. Stanley. *Acoustic Impacts of Offshore Wind Energy on Fishery Resources*. Tethys, Pacific Northwest National Laboratory, 2020. PDF, <https://tethys.pnnl.gov/sites/default/files/publications/Mooney-et-al-2020.pdf>

⁶³ U.S. Offshore Wind Synthesis of Environmental Effects Research (SEER). *Underwater Noise Effects on Marine Life Associated with Offshore Wind Farms*. Report by National Renewable Energy Laboratory

Some commentators have speculated that seafloor nodule recovery could release large quantities of deep-ocean dissolved carbon dioxide to the atmosphere, or harm seafloor microorganisms that help absorb and store carbon dioxide.⁶⁴ In the former case, future scientific work can aim to quantify the magnitude of CO₂ release, which may be limited considering that production vessels will pump CO₂-rich return water back down to abyssal depths almost immediately. The latter concern is implausible, given that the cycling of CO₂ between the surface ocean and deep ocean reaches 100 billion metric tons of carbon in each direction annually thanks to a powerful combination of physical, chemical, and biological processes that by all indications vastly dwarfs any negligible carbon absorbed by seafloor organisms.^{65,66,67,68} Furthermore, nodule collection operations would only affect small areas of seafloor relative to the immense scale of the abyssal deep, with consequently few impacts on even the relatively minimal biogeochemical cycling mediated by abyssal seabed life planetwide.

Some research has proposed that nodule collection and return water reinjection could dissolve some of the metal content from nodules and release potentially toxic metal pollution into the water column.⁶⁹ This potential effect remains theoretical and requires direct field measurements to verify that any significant risk exists. A single research study published in mid-2024 reported measurements suggesting that seafloor nodules might naturally produce dissolved oxygen in the deep ocean electrochemically.⁷⁰ However, further field experiments are needed to assess the veracity of this hypothesized phenomenon. The study has generated vigorous discussion, with some independent commentators noting potential methodological limitations and sources of

and Pacific Northwest National Laboratory for the U.S. Department of Energy, Wind Energy Technologies Office, January 7, 2022. PDF file. <https://tethys.pnnl.gov/sites/default/files/summaries/SEER-Educational-Research-Brief-Underwater-Noise-Effects.pdf>

⁶⁴ Seaver Wang, “No, Collecting Seafloor Metals Won’t Wreck the Ocean Carbon Cycle,” Breakthrough Institute, July 9, 2024, <https://thebreakthrough.org/issues/energy/no-collecting-seafloor-metals-wont-wreck-the-ocean-carbon-cycle>.

⁶⁵ Bates, Nicholas. *Ocean Carbon Cycle*. January 1, 2019, 418–28. <https://doi.org/10.1016/B978-0-12-409548-9.11598-2>.

⁶⁶ Heinze, C., S. Meyer, N. Goris, et al. “The Ocean Carbon Sink – Impacts, Vulnerabilities and Challenges.” *Earth System Dynamics* 6, no. 1 (2015): 327–58. <https://doi.org/10.5194/esd-6-327-2015>.

⁶⁷ Emerson, Steven, and John Hedges. *Chemical Oceanography and the Marine Carbon Cycle*. Cambridge University Press, 2008. <https://doi.org/10.1017/CBO9780511793202>.

⁶⁸ Nowicki, Michael, Tim DeVries, and David A. Siegel. “Quantifying the Carbon Export and Sequestration Pathways of the Ocean’s Biological Carbon Pump.” *Global Biogeochemical Cycles* 36, no. 3 (2022): e2021GB007083. <https://doi.org/10.1029/2021GB007083>.

⁶⁹ Amon, Diva J., Juliano Palacios-Abrantes, Jeffrey C. Drazen, et al. “Climate Change to Drive Increasing Overlap between Pacific Tuna Fisheries and Emerging Deep-Sea Mining Industry.” *Npj Ocean Sustainability* 2, no. 1 (2023): 9. <https://doi.org/10.1038/s44183-023-00016-8>.

⁷⁰ Sweetman, Andrew K., Alycia J. Smith, Danielle S. W. de Jonge, et al. “Evidence of Dark Oxygen Production at the Abyssal Seafloor.” *Nature Geoscience* 17, no. 8 (2024): 737–39. <https://doi.org/10.1038/s41561-024-01480-8>.

error, critiquing the scope of the original authors' conclusions, and even questioning whether the claimed electrochemical reaction is thermodynamically plausible.^{71,72,73}

In general, seafloor nodule collection systems remain in a relatively early stage of pilot testing and likely allow for considerable innovations that can reduce or even eliminate impacts. Regulators can also set acceptable performance-based limits on parameters like measured metal concentrations in released return water, to enforce responsible practices and require use of mitigating technologies.

While this discussion has largely focused on the potential environmental and ecological effects of polymetallic nodule collection, impacts from commercial-scale mining of deep-sea ferromanganese crusts or seafloor massive sulfides remain relatively less studied but would likely be far more significant. Such resource types would inherently require collector vehicles to excavate and break up seabed rock materials.

Finally, from a security perspective, seafloor mineral prospective sites are often remote, providing natural protection against security threats. However, collector vehicle, riser pipe, and production vessel systems pose single points of failure, increasing vulnerability to hypothetical attacks. Western environmental activists have disruptively targeted pilot testing operations led by Western companies in the past.^{74,75} To date, such activist groups have not sought to interfere with Chinese-led operations using such high-profile tactics.

Risks of Irresponsible Seafloor Minerals Sector Activities

To the best of available knowledge, the Chinese state and Chinese companies have not yet participated in any irresponsible activities related specifically to the collection of deep-sea minerals. In international fora such as the International Seabed Authority, Chinese government

⁷¹ Voosen, Paul. "Claim of Seafloor 'Dark Oxygen' Faces Doubts." *Science* 385, no. 6715 (September 18, 2024): 1258–1259. <https://www.science.org/content/article/claim-seafloor-dark-oxygen-faces-doubts>

⁷² Denny, Alden, Werner Svellingen, and Lars-Kristian Lunde Trellevik. Review of "Evidence of Dark Oxygen Production at the Abyssal Seafloor" by Sweetman et al. Preprint, August 2024. DOI:10.13140/RG.2.2.30239.37289.

https://www.researchgate.net/publication/383037889_Review_of_Evidence_of_Dark_Oxygen_Production_at_the_Abyssal_Seafloor_by_Sweetman_et_al

⁷³ Cuesta, Angel, and Marcel Jaspars. Is Abyssal Dark Oxygen Production Even Possible at All? March 10, 2025. <https://eartharxiv.org/repository/view/8736/>.

⁷⁴ Daniel Shailer. "Environmental Protesters Board Deep-Sea Mining Ship in Middle of Pacific Ocean." NBC Bay Area, November 26, 2023. <https://www.nbcbayarea.com/news/national-international/environmental-protesters-board-deep-sea-mining-ship-in-middle-of-pacific-ocean/3381484/>.

⁷⁵ Greenpeace International. "LIVE from Pacific #4: Our Mission to Stop Deep Sea Mining before It Begins!" November 12, 2025. <https://www.greenpeace.org/international/story/47781/live-from-pacific-4-our-mission-to-stop-deep-sea-mining-before-it-begins/>.

representatives are currently seeking to cultivate China's image as a responsible major power, emphasizing the contrast between orderly Chinese participation in ISA dialogues relative to actions like the U.S.'s recently announced intent to unilaterally license and permit mineral exploration and recovery operations in international waters under existing U.S. laws.⁷⁶ Many other countries have reacted to this 2025 announcement with alarm, viewing U.S. intentions as a threatening challenge to the seafloor mineral governance provisions of UNCLOS, to which the U.S. is not a party.^{77,78,79}

At the same time, a number of past events and incidents suggest that the U.S. and allied partners should consider the possibility that Chinese actors could illegally target seafloor mineral deposits or use such activities as cover for military intelligence-gathering purposes.

Recent reporting has highlighted the potential use of Chinese civil and academic research vessels to conduct clandestine high-resolution bathymetric surveys of sensitive strategic waters, such as areas off Taiwan's eastern coast and large regions east and west of U.S. military installations on Guam.⁸⁰ Some of this survey work may be performed not just at the destination of a given voyage, but also during portions of research vessel transit to and from the principal area of study for a given scientific expedition.

In the past, Chinese ships apparently from the private maritime sector have conducted illicit operations to steal seafloor resources in shallower waters. Notably, Chinese salvage operations have historically targeted the wrecks of military vessels sunk during the Second World War in order to harvest high-value items like bronze propellers and pre-atomic steel containing low

⁷⁶ Paik, Kathryn, and Gracelin Baskaran. Does the U.S.–Cook Islands Seabed Minerals Announcement Signal a New Front in Great Power Competition? August 20, 2025. <https://www.csis.org/analysis/does-us-cook-islands-seabed-minerals-announcement-signal-new-front-great-power-competition>.

⁷⁷ Elisabeth Braw. "Mining without Rules: The Risky US Bet on the Deep Sea." Atlantic Council, February 9, 2026. <https://www.atlanticcouncil.org/in-depth-research-reports/issue-brief/mining-without-rules-the-risky-us-bet-on-the-deep-sea/>.

⁷⁸ AFP. "Trump's deep-sea mining order violates global norms: France." AFP, April 28, 2025. <https://www.france24.com/en/live-news/20250428-trump-s-deep-sea-mining-order-violates-global-norms-france>

⁷⁹ Robert Hodgson. "European Commission questions legality of US seabed mining plans." Euronews. April 28, 2025. <https://www.euronews.com/my-europe/2025/04/28/european-commission-questions-legality-of-us-seabed-mining-plans>.

⁸⁰ Buckley, Chris, and Agnes Chang. "China's Research Ships Frequently Survey Off Taiwan and Guam, New York Times Reports." The New York Times, July 10, 2025. <https://www.nytimes.com/2025/07/10/world/asia/china-ships-taiwan-guam.html>

levels of radioactivity, due to the metal pre-dating postwar nuclear weapons testing.^{81,82,83} Such practices, also involving illegal salvage crews from other countries, have forced many naval archeological expeditions to conceal the locations of discovered wrecks in an effort to protect these war graves from destruction. At the same time, the Taiwanese Coast Guard reports a regular pattern in which thousands of Chinese-flagged vessels each year are illegally harvesting valuable coastal sand from Taiwanese territorial waters, presumably for construction purposes.^{84,85}

Such risks emphasize the value of designing proactive measures in conjunction with allies to track, intercept, and deter ships conducting illegal economic activities at sea. Though seafloor minerals currently remain a nascent economic sector, planners should nevertheless consider how the U.S. and partner countries ought to protect their seafloor mineral claims and operations.

Dual-Use Applications of Seafloor Mineral Sector Technologies

The list of categories of naval technology that potentially benefit from growing progress in and experience with seabed vehicles, collector systems, and supporting capabilities necessary for successful seabed mineral operations is likely longer than the list of naval topics with no dual-use relationship to seabed mining. Mineral exploration and recovery will necessarily involve coordinating data from and operation of fixed seabed instruments, seabed vehicles, and submersible platforms in extreme environments where efficient and reliable operation convey fundamental economic advantages. Design specifications for such technologies will overlap heavily with military requirements across a variety of applications. Meanwhile, engineers, technicians, and operators with experience in the seafloor minerals sector will undoubtedly offer a valuable pool of talent for naval priorities moving forward.

⁸¹ Grady, John. "U.K. Royal Navy 'Distressed and Concerned' by Illegal Chinese Salvage of WWII Wrecks." USNI News, May 25, 2023. <https://news.usni.org/2023/05/25/u-k-royal-navy-distressed-and-concerned-by-illegal-chinese-salvage-of-wwii-wrecks>

⁸² Holmes, Oliver, Monica Ulmanu, and Simon Roberts. "The World's Biggest Grave Robbery: Asia's Disappearing WWII Shipwrecks." The Guardian, November 3, 2017. <https://www.theguardian.com/world/ng-interactive/2017/nov/03/worlds-biggest-grave-robbery-asias-disappearing-ww2-shipwrecks>

⁸³ Catterson, S. E. "Still on Patrol: An Argument for Greater Protections for Sunken Naval Vessels and Other Underwater Military Remains." St. John's Law Review (2022). <https://scholarship.law.stjohns.edu/cgi/viewcontent.cgi?article=7193&context=lawreview>

⁸⁴ Braw, Elisabeth. "China Is Stealing Taiwan's Sand." Foreign Policy, February 19, 2026. <https://foreignpolicy.com/2022/07/11/china-stealing-taiwan-sand/>.

⁸⁵ Nikkei Asia. "Line in the Sand: Chinese Dredgers Are Stealing Taiwan, Bit by Bit." Accessed February 18, 2026. <https://asia.nikkei.com/spotlight/the-big-story/line-in-the-sand-chinese-dredgers-are-stealing-taiwan-bit-by-bit>.

Table 2: Hypothetical list of naval undersea capabilities and technologies potentially benefiting from the adaptation of dual-use technologies from a mature seafloor minerals sector.

- | | |
|---|---|
| <ul style="list-style-type: none">● Unmanned vehicle launch and recovery systems● Manipulator arms and tools● Minelaying and minesweeping● Air-sea rescue and undersea rescue● Underwater digital twin simulations● Underwater energy harvesting devices for AUVs and autonomous platforms● AUV and seabed vehicle propulsion● Precise underwater navigation● Shallow-water Anti-Access/Area Denial capabilities (e.g. bottom-moored weapons, armed AUVs)● Offshore and subsea engineering | <ul style="list-style-type: none">● Underwater infrastructure defense, monitoring, and sabotage● Underwater sensor packages and target acquisition (e.g. synthetic aperture sonar, LiDar)● AI for undersea systems, operations, and multi-platform coordination● Pressure-tolerant, extreme environment batteries, fuel cells, and radioisotope power systems● Underwater surveying and mapping● Advanced uncrewed undersea vehicle design, materials, and capabilities● Specialist human capital development |
|---|---|

In terms of seabed platforms and infrastructure, commercial-scale seafloor mineral activities will in many respects mirror past and present deployments of sensor networks for naval purposes. A notable historical example is the Sound Surveillance System (SOSUS) of passive sonar hydrophones placed across the Greenland-Iceland-United Kingdom gap in the North Atlantic Ocean for the purpose of detecting passing Soviet submarines during the Cold War. More recently, China has invested in deploying seafloor infrastructure in coastal waters via efforts referred to as an “Underwater Great Wall / Underwater Observation Network” (水下长城 / 水下观测网), aiming to secure the waters surrounding strategic naval anchorages off China’s coast, such as near the country’s nuclear submarine base on Hainan Island in the South China Sea.⁸⁶

Meanwhile, the demanding abyssal conditions and exacting geospatial requirements of seafloor mineral exploration and collection will likely help advance the development of uncrewed undersea vehicles in numerous dimensions ranging from advanced onboard power systems to navigation to materials to autonomous operation. As naval applications are primarily focused on shallower depths such as strategic coastal waters or the uppermost 1.5 kilometers of the open ocean, adaptations from deep-ocean vehicles may confer disproportionate advantages in aspects

⁸⁶ Goldstein, Lyle J. “China Is Building a ‘Undersea Great Wall’ To Take on America in a War.” *The National Interest*, October 27, 2019. <https://nationalinterest.org/blog/buzz/china-building-undersea-great-wall-take-america-war-90601>

like range, power, durability, and situational awareness. Some of these capabilities may in turn benefit and benefit from advances in space technologies, creating linkages between the seafloor minerals sector and the mission and responsibilities of the U.S. Space Force.

The abyssal ocean itself, at depths of three to five kilometers, is unlikely to become a highly kinetic environment in a near future military conflict given the shallower depths that existing submarines and naval weapon systems are designed for. Weapon range, engineering, and targeting limitations likely prevent the effective deployment of armed torpedo-based mines or similar systems on the abyssal seafloor for the foreseeable future. Nevertheless, seabed mining capabilities would certainly facilitate operations targeting transoceanic pipeline, power, or telecommunications infrastructure at abyssal depths.

Given the underwater nature of mineral exploration and recovery, it is more difficult to imagine dual-use applications from the seafloor minerals sector with applications relevant to naval surface warfare, air defense, or naval air operations.

Overall, if Chinese institutions and corporations take a commanding lead in next-generation undersea vehicles and moored seabed platforms, this would only further exacerbate disadvantages the U.S. Navy already faces: a conventional naval shipbuilding disparity and the geographical and logistical challenges of operating in distant contested waters of the Indo-Pacific.

Figure 4: a) Boeing Extra Large Uncrewed Undersea Vehicle (XLUUV) units under construction. b) Conceptual drawing of a torpedo-armed, bottom-moored homing mine in operation. c) Lockheed Martin conceptual illustrations of ride-along capable, self-recharging Lamprey Multi-Mission Autonomous Undersea Vehicle (MMAUV). d) Autonomous Underwater Vehicle (AUV) recovery by the Monterey Bay Aquarium Research Institute aboard the research vessel *R/V Rachel Carson*.

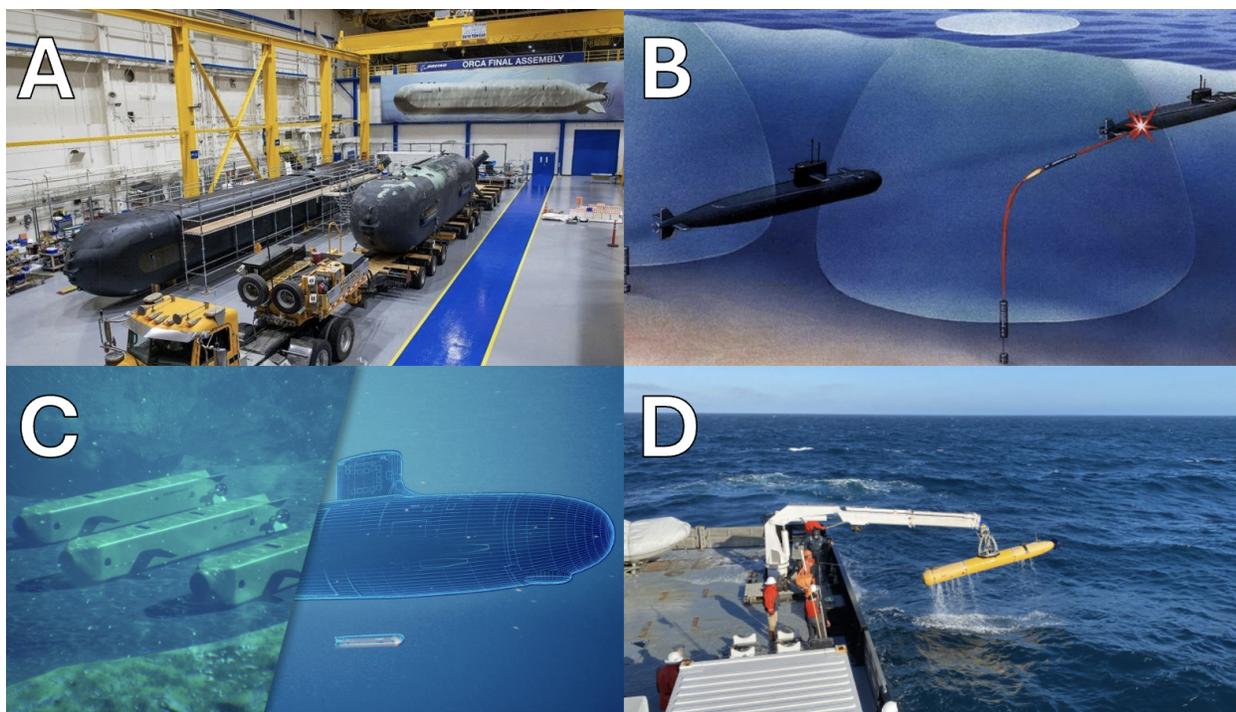
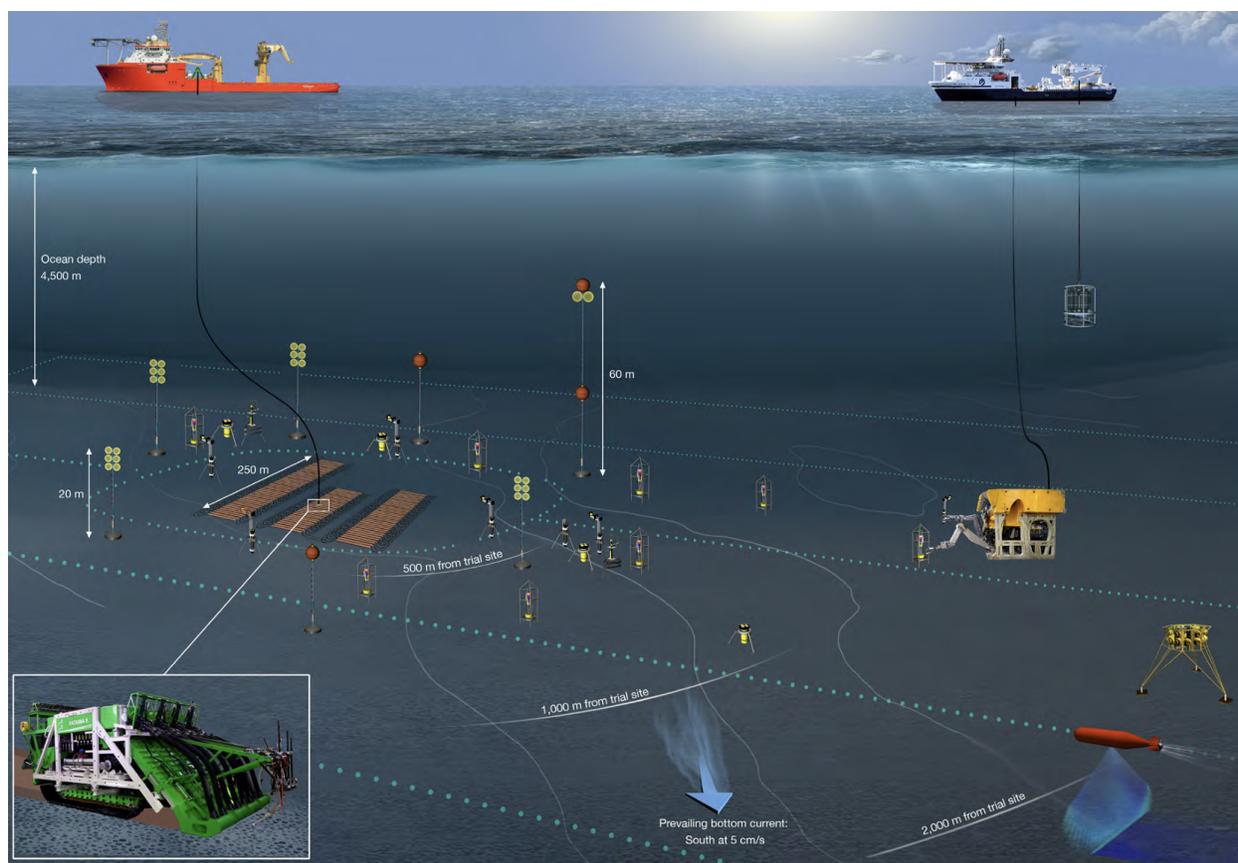


Figure 5: Illustration depicting a Global Sea Mineral Resources NV (GSR) seafloor nodule collection test conducted in 2021 in the Clarion-Clipperton Fracture Zone. Note the extensive supporting deployment of seabed instruments, piloted submersible rovers, and autonomous underwater vehicles over many square kilometers of seafloor and deep ocean in addition to the pre-prototype collector vehicle and umbilical system, even for this relatively limited pilot-scale test.



Priority Areas for U.S. Cooperation With Allies and Partners

Organization of downstream consuming sectors

In conjunction with the development of processing technologies and processing plants capable of handling polymetallic nodule feedstocks, it is an urgent priority for the United States and allied countries to coordinate the downstream industries that would consume recovered nickel, cobalt, manganese, and copper, thereby building interest in and willingness to source seafloor metals.

Currently, several factors potentially impede the establishment of healthy demand signals for seafloor minerals. First, a number of primarily Western automakers, battery manufacturers, and other companies have issued or signed commitments that they will avoid procuring seabed minerals—at least until further scientific research has established that companies can collect seafloor minerals with acceptable levels of environmental impacts. Second, the growing global market share of nickel-free and cobalt-free lithium iron phosphate (LFP) and lithium manganese iron phosphate (LMFP) battery chemistries have created some uncertainty about future demand from the nickel manganese cobalt (NMC) battery cathode active material sector as a high-value market for polymetallic nodule metals. This concern also reflects plateauing investment in new lithium-ion battery supply chain manufacturing capacity in the United States⁸⁷ and competitiveness challenges facing Europe’s battery manufacturing sector,⁸⁸ with these two markets heavily driving NMC battery material demand.⁸⁹

The U.S. and allied governments could help create greater clarity surrounding both of these factors. To address reluctance to procure seabed minerals, agencies, federal scientists, and policymakers could convene with downstream industries to better understand the scientific knowledge thresholds at which companies would feel comfortable sourcing nodule materials, better educate corporate decision-makers on the current state of technologies and environmental analyses, and collect input to guide near-term scientific expeditions that help fill the most salient knowledge gaps. Meanwhile, governments can also foster clearer demand signals for NMC battery materials by aggregating expected public sector procurement needs (e.g. defense sector battery technologies, fleet electric vehicles and trucks, public transportation), and by strengthening and coordinating incentives targeting the battery sector.

Processing technology and facilities

Metallurgical processing ranks as another top priority for the U.S. to pursue in cooperation with overseas partners. Again, firms have yet to demonstrate commercial-scale processing flowsheets for recovering metals from harvested seafloor polymetallic nodules.

While it is possible to envision that a future U.S. processing plant could specialize in nodule materials, considerations like energy costs, facility development costs, regulatory timelines,

⁸⁷ Yusko, Katherine. “Charging Ahead: How the U.S. Can Close the Gap in the EV Race.” White paper, American Security Project, August 14, 2025. <https://www.americansecurityproject.org/charging-ahead/>

⁸⁸ Panday, Amit. “Why Europe Is Losing the Gigafactory Race to China.” S&P Global Automotive Insights, August 2025. <https://www.spglobal.com/automotive-insights/en/blogs/2025/08/why-europe-is-losing-the-gigafactory-race-to-china>

⁸⁹ Lombardo, Teo, Leonardo Paoli, Araceli Fernandez Pales, and Timur Gül. “Global Battery Markets Are Growing Strongly – and So Are the Supply Risks.” International Energy Agency Commentary, February 13, 2026. <https://www.iea.org/commentaries/global-battery-markets-are-growing-strongly-and-so-are-the-supply-risks>

logistics, technical expertise, financing, and supporting policies incentivize partnering governments to consider how to best maximize comparative supply chain advantages. Processing facility outputs like battery-grade cobalt sulfate and manganese silicate also require further downstream processing to produce battery cathode active materials and metal alloys. Additionally, countries building processing plants may benefit considerably from overseas technical and engineering expertise, whereas countries consuming recovered metals benefit from greater security of supply. Such aligned national interests create fertile ground for formal partnerships that can strengthen capabilities across the supply chain, such as testing of processing approaches at the pilot plant scale and joint financing of commercial-scale facilities.

Coordinated national regulatory development

The United States can help increase the competitiveness of an ex-China seafloor minerals sector by working together with both new and traditional partners to develop more similar national regulations for seafloor mineral collection, particularly in sovereign national waters. Some countries like Pacific small island developing states may possess sizable EEZ territories with promising prospective seabed resources but may lack the capacity or expertise to independently develop comprehensive regulatory and permitting regimes for seafloor mineral activities.

Bilateral or multilateral efforts to assist promising overseas partners with domestic seafloor mineral regulatory rulemaking may speed progress in the sector and encourage broader partnerships with the U.S. In any event, future seafloor mineral operators will find it easier to navigate different national jurisdictions if regulations share commonalities across procedures and practices, legal requirements, environmental standards, and other aspects.

Joint development of undersea vehicles and technologies

Further advances in deep-sea technologies could substantially improve the economics and potential scale of seafloor mineral recovery, both through improvements to the collector vehicle and riser pipe recovery model as well as through breakthroughs in alternative approaches, such as robotic manipulator arm recovery, or transport of materials to the surface using hoppers or mechanical lift systems.⁹⁰ Certain capabilities—such as hovering collector vehicles, basic collector vehicle water treatment, and increased operational speed and volume—may also improve environmental management by reducing or eliminating certain environmental impacts and minimizing the duration of operations in a given area. Particularly given the dual-use value

⁹⁰ Gunasekara, Oliver. "How Impossible Metals' Next-Gen Technology will Drive Sustainable and Responsible Deep-Sea Critical Minerals Collection." Offshore Technology Conference. 2025.

of undersea technologies, cooperation with trusted allies to develop and test such platforms considerably advances the interests of the United States.

Maritime rapid-response frameworks

As seafloor mineral recovery approaches improve and proliferate, some smaller or less-developed countries may lack the capacity to prevent illicit mineral harvesting in their territorial waters. Other countries may face increasing risks from illegal mineral collection as a form of grey zone geopolitical coercion or harassment. Finally, mineral concessions in international waters under the ISA or U.S. frameworks may similarly compel countries to assert their maritime interests and deter efforts to interfere with ongoing operations on the high seas. The U.S. should coordinate efforts with allies to develop maritime rapid-response procedures for protecting seafloor resources, and could offer related assistance to new partner countries as part of broader seafloor mineral cooperative agreements.

Scientific surveying and analysis

Leveraging existing U.S. strengths in oceanographic science, the U.S. can accelerate progress in the seafloor mineral sector by establishing bilateral and multilateral science campaigns to conduct mineral exploration, perform environmental impact analyses, and extend technical assistance to overseas allied and partner countries. In particular, resource surveys may uncover previously unknown, high-value mineral deposits, such as dense nodule fields, that would dramatically alter the known geography and relative economic balance of power in the seafloor minerals sector.

Recommendations for the Commission and for the U.S. Congress

Topics for the Commission to monitor:

- **Developments at the International Seabed Authority.** The Commission should observe the ongoing proceedings at the ISA, particularly the international body’s meetings this year, and assess whether the ISA makes meaningful progress towards finalizing its Mining Code. In particular, the ISA may accelerate its regulatory development efforts in response to President Trump’s 2025 executive order *Unleashing America’s Offshore Critical Minerals and Resources*,⁹¹ perceiving a risk that industry progress under the U.S. framework may encourage other member states to defect from a comparatively deadlocked international governance regime. On the other hand, the Commission should closely monitor ISA proceedings that seek to censure the United States and companies pursuing mineral exploration and recovery under U.S. laws. An especially important consideration is how ISA member countries party to UNCLOS interpret their obligations under the treaty to avoid aiding or assisting activities that contravene the treaty’s provisions on mineral resources, a legal responsibility emphasized by a number of international legal scholars and practitioners.^{92,93}
- **General sentiment towards seafloor minerals among the general public, corporate stakeholders, and overseas governments.** Patterns of public openness and opposition to seafloor polymetallic nodule exploration and recovery have and will continue to play a key role in shaping both regulatory and commercial developments in this sector. As evidenced by the distribution of critical versus supportive public comments received by NOAA in the process of revising its regulations for issuing exploration licenses and recovery permits in late 2025, opposition from civil society organizations and members of the general public remains vigorous.⁹⁴ In the context of the ISA, advocacy

⁹¹ United States, The White House. *Unleashing America’s Offshore Critical Minerals and Resources: Executive Order*. April 24, 2025. <https://www.whitehouse.gov/presidential-actions/2025/04/unleashing-americas-offshore-critical-minerals-and-resources/>

⁹² Lathrop, Coalter G., and Franka Nodewald. “Reclaiming Authority: Forcing Seabed Mining Contractors to Choose between the ISA and the USA.” EJIL: Talk! (blog), December 9, 2025. <https://www.ejiltalk.org/reclaiming-authority-forcing-seabed-mining-contractors-to-choose-between-the-isa-and-the-usa/>

⁹³ Vidas, Davor. “Untouchable Metals: How the Obligations of UNCLOS States Parties Limit the Commercial Viability of Unilateral Deep-Sea Mining.” EJIL: Talk! (blog), July 16, 2025. <https://www.ejiltalk.org/untouchable-metals-how-the-obligations-of-unclos-states-parties-limit-the-commercial-viability-of-unilateral-deep-sea-mining/>

⁹⁴ National Oceanic and Atmospheric Administration. *Deep Seabed Mining: Revisions to Regulations for Exploration License and Commercial Recovery Permit Applications*, 91 Fed. Reg. 2642–2677 (January

organizations have pushed strongly for a moratorium on seafloor mineral activities pending further scientific study—a proposal that has now secured support from a list of 40 countries.⁹⁵

From a critical mineral supply chain security perspective, determined popular opposition to seafloor minerals may lead to several possible outcomes. Scenarios range from a near-to-medium term failure to commercialize polymetallic nodule collection that perpetuates existing Chinese supply chains, to a Chinese-led nodule recovery sector that even further reinforces Chinese dominance of these metal commodities.

- **Announced Chinese seafloor mineral partnerships and agreements.** The Commission should devote attention towards cataloguing Chinese government-to-government outreach that involves seafloor minerals as a topic of negotiations or as an area of cooperation. Particularly given regulatory deadlocks at the ISA, cooperative partnerships with countries that possess prospective seafloor mineral resources in their EEZ waters may become the fastest route for companies to commence commercial-scale recovery operations. Announcements of bilateral cooperative efforts between China and partner countries to explore and exploit polymetallic nodules or other resources will likely signal important and accelerating developments in this sector.
- **Seafloor mineral exploration in the contested Arctic.** The shallow Arctic Ocean remains relatively poorly surveyed for seafloor minerals, yet may yield deposits at depths that enable more economically favorable exploitation. At the same time, many regions of the Arctic are currently subject to contested sovereign claims, falling outside the ISA’s jurisdiction over international waters and raising the risk of geopolitical and maritime disputes over resources within such areas. New surveying activity in the Arctic and announcements regarding resource discoveries may further intensify international attention on this strategic ocean region.
- **Financial and investment trends in the nascent seafloor minerals sector.** Companies seeking to explore and exploit seafloor minerals are ultimately competing against conventional terrestrial operations in global commodity markets and have yet to begin producing commercial output or revenue. While private sector investment to date has supported increasingly ambitious technology development, testing, exploration, and policy momentum towards commercial-scale recovery, changes to this trend could significantly discourage commercialization efforts, in turn impacting the relative

21, 2026). <https://www.federalregister.gov/documents/2026/01/21/2026-01044/deep-seabed-mining-revisions-to-regulations-for-exploration-license-and-commercial-recovery-permit>

⁹⁵ Deep Sea Conservation Coalition. “Momentum for a Moratorium.” Deep-Sea Conservation Coalition. Accessed February 2026. <https://deep-sea-conservation.org/solutions/no-deep-sea-mining/momentum-for-a-moratorium/>

attractiveness of seafloor minerals as a near-to-medium term opportunity to bolster critical minerals security.

Legislative opportunities for the seafloor minerals sector

Overall, the U.S. faces several significant structural disadvantages that impede the country's ability to benefit from seafloor minerals in practice. First, the unilateral approach of UNCLOS non-ratification long practiced by the United States and strongly reaffirmed under President Trump, exposes the U.S. to international criticism, impedes cooperative efforts with allies and partners, and intensifies already stubborn opposition from environmental and civil society groups. Potentially conflicting resource claims in international waters further exacerbate risks of maritime confrontations and international crises, including interference and grey zone operations that could significantly degrade the economics of commercial recovery in practice. Second, the U.S. does not possess processing capacity capable of extracting metals from nodule materials and could still further develop downstream capacity to produce value-added products like battery active materials and industrial metals. In addition, the reliable and efficient operation of seafloor nodule recovery systems remains unproven at commercial scale.

The below recommendations seek to address these twin categories of geopolitical risks and gaps in technological capabilities.

- **Convene top scientists to collect expert input on performance-based regulatory standards.** Recognizing the value of moving quickly to establish responsible regulatory guidelines that strengthen public support and appropriately steer prospective operators towards better environmental and economic performance, Congress should rapidly fund and organize a study that brings together leading ocean and environmental scientists to formulate recommendations on substantive environmental standards that NOAA and the Bureau of Ocean Energy Management (BOEM) should consider adopting to define preliminary operational thresholds across relevant categories of environmental impacts that seafloor mineral exploration and recovery may potentially cause. Congress should direct such a study to design standards that are technology-inclusive, risk-informed, and performance-based, and include but are not limited to the following impact categories:
 - Return water composition and particulate density
 - Return water particular plume extent and duration
 - Return water reinjection practices
 - Production vessel wastewater releases
 - Seawater quality changes measured just above the seafloor, at the ocean surface, and throughout the water column

- Collector vehicle plume density, spatial extent, and duration
 - Depth of seafloor sediment disturbance
 - Seafloor sedimentation rates caused by seafloor mineral operations
 - Collector system subsea noise measured at the seafloor and throughout the water column
 - Subsea noise impacts from sonar operations
 - Subsea light emissions
 - Outgassing of dissolved gases contained within deep ocean water
 - Limits on nodule collection rates in exploited areas and on the permissible extent of exploited areas within a claim
 - Environmental baselining requirements to proactively survey and assess seafloor ecological impacts as part of environmental impact assessments
 - Adaptive management planning requirements to proactively reduce and avoid impacts on ecologically rich seafloor areas
 - Emergency planning and response requirements in the event of marine spills, vessel collisions, equipment failure, loss of equipment, and other contingencies
- **Appropriate funds to support agency seabed mineral resource mapping plans.** Building on the Trump Administration’s executive order directing NOAA, the Department of Commerce, the Department of the Interior, and the State Department to develop a seabed mapping plan prioritizing areas of the United States Outer Continental Shelf, Congress should appropriate funding for BOEM and the U.S. Geological Survey to continue expanding the National Offshore Critical Mineral Inventory, commensurate with budgetary requests at both agencies over coming years. Congress should consider directing BOEM and the USGS to particularly prioritize seabed surveys in the EEZ regions off the U.S. Minor Outlying Islands in the Pacific Ocean.
 - **Support dual-use underwater vehicle and technology testing.** Congress could request that the U.S. Navy consider the potential for the Navy’s research and development strategies to leverage the seafloor minerals sector as part of broader efforts to advance unmanned undersea vehicles, mines, seabed platforms, and related technologies, systems, and capabilities. While the objectives and expertise of prospective seafloor mineral operators may differ considerably from those of traditional defense contractors and ocean engineering firms, policymakers should not discount the future potential for seafloor mineral companies to usefully contribute to competitive evaluations for new technologies.
 - **Pilot processing of polymetallic nodules.** Congress should authorize appropriations to the Department of Energy to support competitive grant awards to National Laboratories, universities, and private companies for the demonstration of polymetallic nodule

metallurgical processing approaches that yield nickel, cobalt, copper, manganese, and other critical minerals in forms and at a level of purity suitable for use in subsequent manufacturing. Such a program should prioritize processing approaches that offer advantages for adoption at full commercial scale by a facility receiving at least 1 million dry metric tons of nodules per year, and should additionally prioritize processing techniques that yield battery-grade nickel, cobalt, and manganese raw material commodities.

- **Environmental monitoring and impacts assessment.** Congress should authorize appropriations to NOAA to support competitive grant awards that fund oceanographic expeditions intended to assess techniques for mitigating environmental impacts associated with seafloor mineral recovery, to evaluate potential biodiversity risks from seafloor mineral activities, and to study environmental impacts associated with seafloor mineral activities over timescales ranging from immediate impacts to effects up to 5 years post-disturbance. This program should prioritize seabed regions and impact studies associated with polymetallic nodules and nodule recovery technologies.

- **Update and reform provisions of the Deep Seabed Hard Mineral Resources Act.** Dating back to 1980, DSHMRA contains a number of provisions that may pose unnecessary obstacles to efficient development of a seafloor minerals sector.
 - Congress should in particular consider revising DSHMRA restrictions that require U.S. processing of recovered polymetallic nodules barring approval of a special exception by the president or NOAA Administrator. This language could be updated to specify that seabed minerals collected through a U.S. license cannot pass through or be exported to a Foreign Entity of Concern, adding greater flexibility for international partnerships.
 - Congress should remove the requirement that all production vessels and at least one transportation vessel participating in seafloor mineral must be documented under the laws of the United States. Vessels engaging in commercial polymetallic nodule collection are likely to be specially designed or modified for such operations, meaning that no U.S. Flag vessels are available to conduct such activities for the foreseeable future. Such restrictions are likely to impose prohibitive cost, lead time, and vessel availability obstacles upon this emerging industry and may again constrain international partnerships.
 - Congress could revise DSHMRA to place greater guardrails on existing NOAA and presidential discretion to suspend activities, impose special terms on activities, or determine the outcome of license applications—provisions which currently give the president and NOAA Administrator considerable authority to arbitrarily revoke or deny industry activities.

- **Clarify that international seafloor minerals that arrive in the U.S. or eligible partner countries qualify as domestic content.** For the purposes of existing laws such as the foreign material assistance thresholds outlined under the One Big Beautiful Bill Act and for future legislative proposals, Congress should clarify in statute that seafloor minerals recovered from seabed areas beyond national jurisdiction but brought to the United States (or relevant allied, partner, or free trade countries) as their first port of call ought to qualify as U.S. mine production (or allied, partner, or free trade agreement country mine production) for the purpose of determining eligibility under federal policies and incentive programs and for trade purposes.