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Deep Ocean Forum

White Paper:

Business Cases & Financing For Regenerative Use Of The Deep Ocean

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About This Report

Context setting

The deep ocean, typically defined as marine areas below 200 meters depth, covers more than half the planet yet remains one of Earth's least explored and least understood regions. This vast, dark realm is home to extraordinary ecosystems and life forms, from bacteria-farming crabs to millennia-old corals, many of which play critical roles in regulating the planet's climate, cycling nutrients, storing carbon, and generating oxygen. These services are foundational to life on Earth and must be treated as essential to both environmental and human well-being[1].

Despite its significance, the deep ocean is under growing pressure. Overfishing, habitat destruction from resource extraction, climate change, and pollution from plastics and chemicals are converging to stress and potentially shift deep-sea ecosystems. These challenges are unfolding in a fragmented governance landscape with limited regulatory clarity, and, critically, with inadequate and highly concentrated funding. The high costs of accessing and researching the deep ocean have led to major knowledge and data gaps, hampering both science and governance. Today, much of the available capital remains siloed in government or academic budgets, with an unbalanced share sitting in industry without structured pathways for broader public benefit. Mobilizing new funding streams and alternative financing models will be essential to close these gaps and enable responsible stewardship. Other frontier sectors, such as space exploration, offer useful parallels, where innovative public-private partnerships have dramatically expanded investment, infrastructure, and knowledge generation.

"The Deep Blue Initiative" was launched in October 2024 to become a global collective that aims to accelerate deep-ocean research, conservation, and public engagement. At this moment the "Deep Blue Initiative" is a forum to foster meaningful conversations and connect individuals, existing networks, and communities across various disciplines and sectors doing work in the deep sea. The overarching goal is to identify current priorities and pave the way toward collective solutions for these most pressing challenges related to the deep sea.

One of three priorities that emerged from these initial community discussions is the proposal to explore the prospect of establishing an investment or hybrid fund for the deep ocean, referred to as "The Deep Ocean Fund". The Deep Blue Initiative has provided the first groundwork for this endeavor by collating visions, perspectives and proposals from the community of participants, mainly from academic, governance, consultancy backgrounds (**Textbox 1**). Discussions have also resulted in a preliminary list of scientific discoveries, technological innovations, science and governance needs that may serve as avenues for emerging industries and to be built. Among others, the list highlights the potential of deep-sea access and sensing technologies, big-data processing and modelling technologies (including digital twinning and machine learning developments), biotechnological and biomedical tools and discoveries (including metabarcoding aka environmental DNA applications, and characterization of extreme environments lifeforms), bio- and nature-inspired designs, and sustainable marine food and resource production through aqua culture (from algae to fish). These emerging priorities are taking shape at a time when the global governance and market landscape is evolving rapidly. This creates both an enabling context and a strategic window to advance new economic models and innovation pathways for the deep ocean.

Momentum is also visible in international policy. The 1982 United Nations Convention on the Law of the Sea (UNCLOS) laid the foundation for ocean governance. More recently, negotiations under the Biodiversity Beyond National Jurisdiction (BBNJ) Agreement have made substantial progress toward a global framework for biodiversity protection in international waters. While such emerging regulation will introduce new requirements for industry, it is also expected to generate new market opportunities, driving demand for environmental monitoring, ocean data services, and enabling technologies to support sustainable governance. Similar dynamics have been observed in other ocean sectors (e.g., offshore wind and aquaculture development) where regulatory frameworks have catalyzed commercial opportunities for monitoring and access technologies. For the deep ocean, this evolving governance landscape could create important incentives for solutions that align business models with emerging information needs.

Emerging technologies and market opportunities are increasingly intersecting with deep ocean innovation. In particular, marine biotechnology, offshore geothermal and geological hydrogen, and marine carbon dioxide removal (mCDR) are gaining attention as potential pathways to generate value while supporting climate, biodiversity, and knowledge goals. These sectors are at different stages of maturity: while marine biotechnology already shows near-term applications, others like offshore geothermal and geological hydrogen remain at an earlier stage of exploration, requiring further research and validation before scaling. This report will explore these opportunities and their readiness in greater depth.

Together, these developments point to a critical opportunity. If designed responsibly, new economic models for the deep ocean can align scientific discovery with regeneration, global equity, and climate resilience. The Deep Blue Initiative aims to help realize this opportunity by advancing concepts of opportunities covering an economic assessment, financial instruments and governance structures for a Deep Ocean Fund. The fund should support actions that protect the deep ocean while generating long-term, shared global value as well as financial returns.

Textbox 1. Deep Blue Initative Report from Virtual Discussions on November 12, 2024:

“The concept of establishing a Deep Blue Investment Fund, aiming to attract private capital for deep ocean ventures, builds on the growing momentum for large-scale ocean and climate funding. While private funding efforts for coral reefs and climate initiatives have gained traction, the deep sea has remained largely overlooked in these discussions. Highlighting the untapped potential of the deep sea and building alignment around its future value will be essential in laying the groundwork for a Deep Blue Investment Fund. Key areas for investment interest include, but are not limited to, deep-sea access technologies, biotechnology, bioinspiration, carbon capture/carbon dioxide removal, fisheries and aquaculture, AI, entertainment and tourism. Aligning industry and academic tech-requirements could provide synergistic opportunities. Further, there exists the opportunity to engage existing ocean-utilizing industries, such as telecommunications, where investments in shared infrastructures could benefit research and conservation endeavors.

Importantly, a Deep Blue Investment Fund will require a clear articulation of market risks and profit margins. A crucial challenge to address will be overcoming the difficulties related to the cost of accessing ocean spaces and shifting the perception of the marine space as a high-risk environment among investors will be essential. Another challenge arises around regulation and ownership in international waters, and implementation of environmental ethics to balance profit motives with sustainable use. As the landscape of existing funds for ocean topics continues to grow (i.e., for coral reefs, mangroves, seaweeds, etc.), we should learn from those experiences to effectively meet these challenges. Blue economies are advancing with or without our involvement. A well-crafted concept published can accelerate and steer private investment toward ethical and sustainable practices and align investments with exploration and science.”

The ‘theory of change’

This report aims to help close critical knowledge and funding gaps that currently constrain the exploration, protection, and responsible use of the deep ocean. Its goal is to broaden the financial rationale for deep ocean stewardship by advancing economic models that depend on and reinforce scientific knowledge. In particular, it focuses on three emerging sectors: marine biotechnology, ocean-based energy, and marine carbon dioxide removal. When developed responsibly, these industries could generate value that supports scientific progress, global equity, and planetary health. The report seeks to pave the way for such sustainable and ethical industries to emerge and to guide private investment toward practices aligned with exploration, conservation, and science.

Global frameworks such as the OECD’s Ocean Economy to 2050[2] have laid important groundwork in mapping the future of ocean-based economies. However, the deep sea remains underrepresented in many of these assessments. The Deep Blue Initiative aims to build on and complement such efforts by providing additional insight into the scientific and regenerative potential of deep ocean systems, and by proposing ways to finance and govern that potential equitably.

The expected output is a strengthened and expanded Deep Blue Initiative. It builds on scientific foundations while activating new coalitions across business, philanthropy, and government. The initiative works with business and finance leaders to co-develop economic narratives that depend on and reinforce deep-sea knowledge and protection. It also supports the development of dedicated funding mechanisms for research, infrastructure, and regenerative innovation pipelines.

This paper contributes to that ambition. It presents a roadmap for building investable pathways grounded in regeneration and proposes financing instruments to help bring them to life. We recognize that conservation imperatives alone may not suffice, especially in the Global South, where governments are rightly seeking economic opportunity. A more viable path links protection with participation in the blue economy, underpinned by science and fairness.

Contents

Executive Summary

This paper outlines a new vision for the deep ocean, one that places shared exploration, scientific understanding, data and information sharing. The ambition is to explore the opportunities and challenges of the deep ocean, spanning discovery, understanding, protection, and sustainable use.

The deep ocean, defined as marine areas below 200 meters and covering more than 66% of the planet, is Earth's largest and least explored ecosystem, with just 0.001% of its seafloor visually surveyed . International agreements such as the BBNJ treaty, advances in biotechnology and marine data, and rising climate imperatives are reframing the deep ocean from an extractive frontier into a foundation for equitable and regenerative value creation.

This report focuses on three frontier industries with strong potential to contribute to regenerative deep ocean use:

- **Marine biotechnology**, already commercially active, offers regenerative co-benefits by transforming deep-sea biodiversity into health, food, and material solutions. However, commercial activities often remain detached from public science and baseline research, raising opportunities to better align industry and academic benefits.
- **Geothermal and geological hydrogen**, while early-stage, could provide firm, low-emission power and strategic economic options for seabed-rich nations.
- **Marine carbon dioxide removal (mCDR)** presents high-risk, high-reward potential to support global carbon goals, if scientific and governance gaps are addressed.

In addition, the report highlights platform technologies, including ocean observation, sampling, and analytics; ocean transportation; and ocean communication, which, while technologically advanced with growing commercial deployment and serving as essential enablers of deep ocean science and responsible industry deployment, are not a primary focus, given their indirect contribution to regenerative outcomes.

For these three focus industries, a common challenge persists: deep ocean innovation lacks the financing architecture required to scale. Most private capital still views these industries as too early, fragmented, or high-risk. Public and philanthropic efforts remain uncoordinated, with critical funding gaps at mid-TRL and early commercial stages.

To close these gaps and build investable pathways, the report proposes three flagship financial instruments:

- A **National Nature Capital Fund** to help countries govern marine biodiversity as a sovereign asset and monetize digital sequence data while reinvesting in science, infrastructure, and benefit-sharing.
- A **Deep Ocean Deep Tech Cluster**, requiring approximately $400—500 million, to co-locate labs, capital, and testing environments, accelerating commercialization of ocean biotech, sensors, and clean energy hardware.
- A **'First-of-A-Kind' Project Finance Facility** to bridge the capital valley for First-of-a-Kind ocean energy pilots through milestone-based loans.

Together, these instruments can shift deep ocean development from speculative to investable. anchoring long-term stewardship, building national capacity, and unlocking regenerative business models.

Key figures to remember:

- **0.001%**: share of deep seafloor visually surveyed[3]
- **$383—717 billion/year**: financing needed to build a sustainable ocean economy by 2030[4]
- **$440 billion**: cumulative market potential for marine biotechnology (2025-2065) *(see **Annex 9.** for details)*
- **$700 billion**: cumulative market potential for offshore geothermal energy (2025-2065) *(see **Annex 9.** for details)*
- **$10 trillion**: cumulative market potential for marine CDR (2025-2065) *(see **Annex 9.** for details)*
- **2026**: critical milestone year for mCDR pilots to generate learning before 2030[5]
- **$400—500 million**: estimated cost over ~10 years to establish a Deep Ocean Deep Tech Cluster *(based on global benchmarks such as The Engine Ventures[6], AstraZeneca[7], and Northvolt Labs[8])*
- **$60+ billion**: estimated capital that could be unlocked if just 0.1% of global SWF & pension funds are directed to FOAK ocean projects[9] [10]

Photo by OceanX

Chapter I. Global context setting - current and future narratives on the deep ocean

Chapter summary: Emerging sectors like marine biotechnology, geothermal and geological hydrogen, and marine carbon removal offer viable pathways to a more regenerative approach. This moment is especially critical, as a wave of global and national initiatives (e.g., BBNJ Agreement, the Nagoya Protocol, emerging national strategies on ABS and marine data infrastructure) are converging to create a window to shape governance, mobilize investment, and steer innovation toward long-term stewardship.For these three focus industries, a common challenge persists: deep ocean innovation lacks the financing architecture required to scale. Most private capital still views these industries as too early, fragmented, or high-risk. Public and philanthropic efforts remain uncoordinated, with critical funding gaps at mid-TRL and early commercial stages.

1.1 Existing narratives around the deep ocean

The deep ocean is increasingly recognized as a global public good, essential to climate stability, biodiversity, and scientific discovery. This chapter highlights the shift in how the deep ocean is framed, from a remote reservoir of untapped resources to a critical domain for stewardship, equity, and innovation, and highlights the governance and financial gaps that must be addressed to unlock its regenerative potential.

a. Framing the deep ocean: scope, knowledge gaps, and a new narrative

The deep ocean is defined in this report as all marine areas deeper than 200 meters, spanning both national waters (Exclusive Economic Zones, or EEZs) and international waters beyond national jurisdiction (ABNJ). Despite its vastness, just 0.001% of the deep seafloor has been visually surveyed. A new narrative is emerging, one that reframes the deep ocean not as a remote frontier for extraction, but as a global public good, essential to biodiversity, climate stability, and long-term human well-being. This evolving perspective has laid the foundation for regenerative approaches grounded in inclusive governance, the conservation of natural capital, and equitable opportunity.

For the purposes of this report, the deep ocean is defined ecologically as marine areas deeper than 200 meters, beginning below the continental shelf and extending into the mesopelagic and abyssal zones. From a regulatory perspective, the scope includes both waters under national jurisdiction (Exclusive Economic Zones, or EEZs) and Areas Beyond National Jurisdiction (ABNJ), commonly known as the High Seas. Based on a proxy of ocean volume distribution provided by GEF, it is estimated that 60—65% of the deep ocean lies within ABNJ[11].

The deep ocean is a vast and extreme environment. Beyond the reach of sunlight, photosynthesis is no longer possible, and life must rely on alternative energy sources. Temperatures are near freezing (typically around 4°C), and oxygen levels can be low (often below 2 mg/L) in deeper or isolated basins. At an average depth of 3,700 meters, pressure exceeds 370 atmospheres (or more than 5,400 psi)[12]. pH levels typically average around 7.8[13] due to the accumulation of dissolved carbon dioxide and the breakdown of sinking organic matter.

It remains one of the least understood ecosystems on Earth. An estimated 1 to 2 million marine species have yet to be discovered[14], and as much as 99% of microbial bioresources remain unknown[15]. According to a study by the Ocean Discovery League, in collaboration with Scripps and Boston University, just 0.001% of the deep seafloor has been visually surveyed. Exploration has been heavily skewed toward the national waters of high-income countries: 65% of deep-sea dives since 1958 have occurred within 200 nautical miles of just three countries (the United States, Japan, and New Zealand), and 97% have been conducted by five high-income nations[16].

Perceptions of the deep ocean are evolving. In addition to its ecological functions, it provides essential ecosystem services (e.g., food, pharmaceuticals, climate regulation, and cultural, educational, and scientific value) and is increasingly recognized as a global public good vital to long-term human and planetary well-being[17] [18]. Deep-sea ecosystems host extremophiles and other unique organisms adapted to high pressure, low temperature, and low light. These life forms offer potential breakthroughs in pharmaceuticals, carbon cycling, and materials science, yet only a small fraction has been studied or sequenced[19].

This evolving narrative carries particular importance for countries in the Global South, including Pacific and island nations that view marine resources as vital to economic sovereignty and development. As expectations surrounding the deep ocean shift, there is growing recognition that future activity must not only minimize harm but actively contribute to restoration and inclusive prosperity. This has laid the foundation for regenerative approaches.

A regenerative approach, in this context, is inclusive and grounded in participatory, transparent governance at multiple levels[20]. It respects the rights of nations and coastal communities and is anchored in the principles of the ecosystem approach. Economically, it recognizes that natural capital cannot be substituted and must be conserved as a core asset. This framing is especially relevant in the deep ocean, where ecosystems take centuries if not millennia to build, where there is limited governance, sparse data, and growing climate pressures create both urgency and opportunity for forward-looking, restorative models.

The regenerative potential of certain ocean sectors is not only ecological but also economic. Studies suggest that sustainable ocean-based solutions can deliver returns at least five times greater than their costs[17]. While these estimates are drawn primarily from coastal ecosystems, they underscore the broader economic rationale for applying regenerative models to deep ocean sectors.

b. Governance and financial landscape between ABNJ and EEZs

Governance and finance in the deep ocean remain deeply fragmented, despite the urgent need to scale solutions. While national waters (EEZs) are governed by domestic ABS frameworks, international waters (ABNJ) lack enforceable mechanisms, stalling cross-border investment. Meanwhile, building a sustainable ocean economy will require $383–717 billion annually by 2030, yet actual funding flows remain just a fraction of that. Without clearer rules and stronger financial coordination, regenerative deep ocean industries risk being left behind in the global climate and biodiversity transition.

The governance of the deep ocean is shaped by a sharp divide between national waters, Exclusive Economic Zones (EEZs), and Areas Beyond National Jurisdiction (ABNJ). EEZs, which account for roughly 39% of the ocean, are governed by national laws often underpinned by international frameworks like the Nagoya Protocol, which sets rules for access and benefit-sharing (ABS) of genetic resources. Several countries, including Indonesia, the Philippines, and Costa Rica, have implemented mature ABS systems that require Prior Informed Consent (PIC) and Mutually Agreed Terms (MAT), offering legal clarity and clearer entry points for investment in marine genetic innovation.

In contrast, ABNJ, which span 60-65% of the ocean, remains under fragmented and incomplete regulation. While the BBNJ Agreement lays out principles for environmental safeguards and benefit-sharing in ABNJ, it is not yet in force, and key operational details are still under negotiation. Instruments such as the London Protocol, which governs ocean dumping and now includes marine geoengineering (e.g., ocean fertilization), offer key environmental safeguards but do not address the governance of marine genetic resources. As a result, no enforceable ABS mechanism yet applies to ABNJ, leaving a gap in legal and investment certainty for international marine research and bioprospecting.

The global ocean economy was valued at $2.6 trillion in 2020 and is projected to reach $3 trillion by 2030[2]. However, building a sustainable ocean economy will require $383–717 billion (mid-point estimate of ~$550 billion) in annual investment through 2030, with financing required to support more and more effective ocean conservation, transition blue economy sectors like seafood, shipping and ports to more sustainable models, and to scale waste infrastructure and ocean-based renewable energy[4].

Annual philanthropic flows to ocean health are around $1 billion per year, largely supporting ocean science, protection and restoration, fisheries and seafood[21]. While still modest, these contributions are growing, having doubled between 2013 and 2023.

Public funding is also limited and increasingly at risk. Official Development Assistance (ODA) aligned with ocean health totaled $1.4 billion in 2021[21]. However, with ODA budgets slashed in many developed markets, future flows remain uncertain.

Across seven assessed Public Development Banks (PDBs) an estimated $4–5 billion per year is committed or disbursed to the ocean economy, with the European Investment Bank (EIB, €7.3 billion between 2019 and 2023) and Agence Française de Développement (AFD, €850 million per year) among the largest contributors[22].

Separately, government expenditure on domestic marine conservation (excluding North America) stands at just $1 billion annually[23]. This pales in comparison to public flows for ocean-negative activities, such as the $22 billion spent each year on harmful fishing subsidies that incentivize overfishing.

On the private side, finance for a sustainable ocean economy is also growing. The number of impact funds with a full or partial focus on the blue economy has increased sixfold since 2015, reaching 164 funds in 2024, spread across private equity (50%), public debt (24%), and public equity (16%)[24].

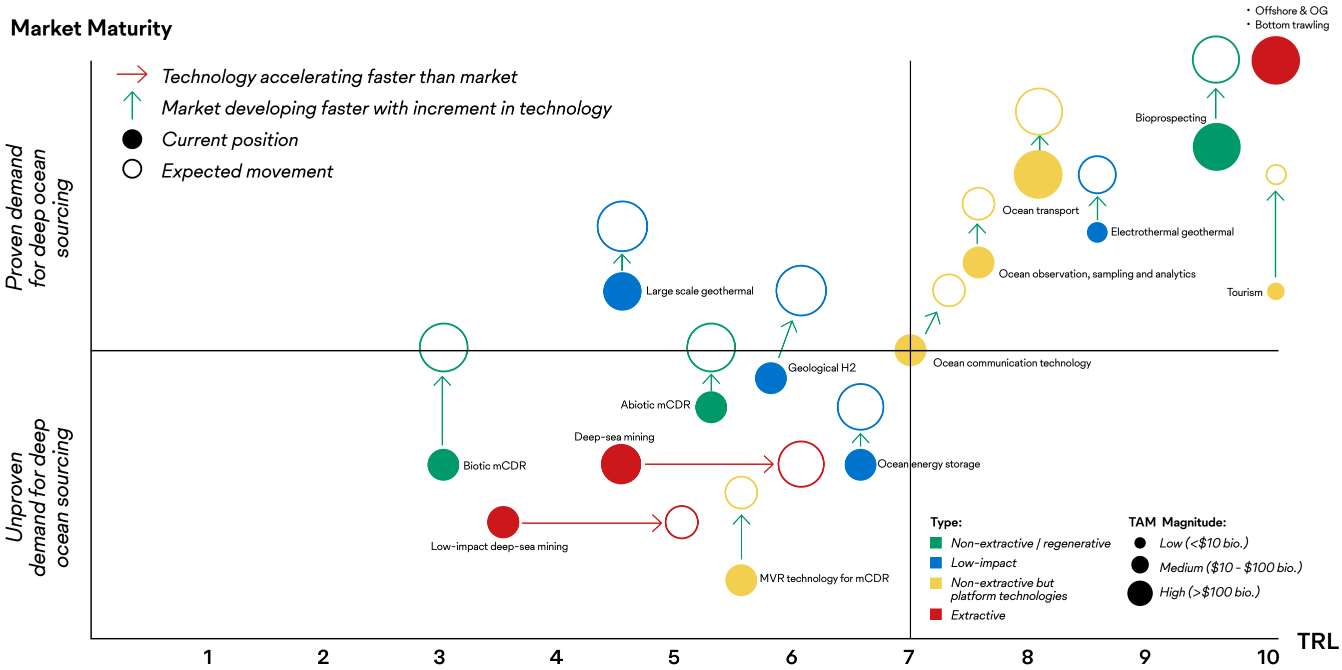
Funding for ocean-climate technologies has lagged behind broader climate investment trends, despite their rising strategic importance. In the U.S., ocean-climate tech startups have raised over $5 billion in venture funding over the past decade. However, this represents only around 2% of total U.S. climate tech investment during the same period[25].

1.2 Overview of different usages of the deep ocean

The deep ocean supports a diverse array of existing and future industrial activities, from long-established extractive sectors to frontier technologies. To identify which sectors can deliver scientific, ecological, and economic value aligned with regenerative principles, this report applies a structured filtering process. The analysis highlights three priority areas, biotechnology, geothermal and geological hydrogen, and marine carbon dioxide removal (mCDR), as the most promising opportunities.

The deep ocean is home to a wide range of industrial activities: extractive sectors such as offshore oil and gas or bottom trawling; emerging regenerative industries like marine biotechnology or carbon removal; and enabling platforms such as ocean transportation, ocean communication technology, and ocean observation, sampling, and analytics.

To identify priority sectors for deeper analysis, a structured filtering process was applied and is illustrated in the matrix below:



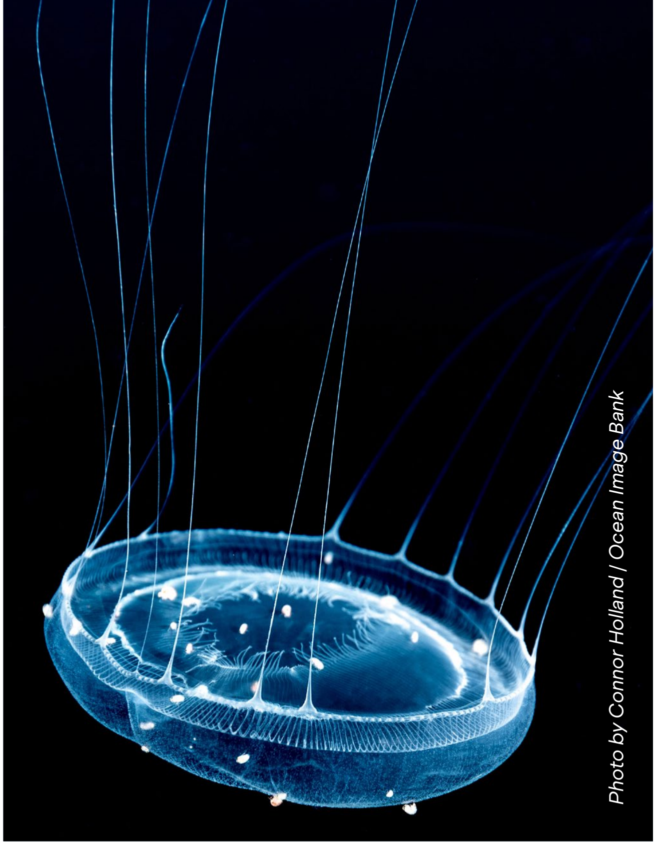
This sector landscape reflects positioning by technological readiness (i.e. TRL 1—10 scale), market maturity (i.e. proven or unproven demand for deep ocean-sourced products or services), and indicative total addressable market (TAM) magnitude. Positioning is based on evidence from **Chapter II.** and **Annex 9.** (for regenerative sectors, low-impact sectors, and enabling platform technologies), and from the **Context on extractive baselines** section within this chapter (for extractive sectors).

Sector categorization:

- **Non-extractive with regenerative co-benefits:**
  Generates value by enhancing ocean knowledge and health, aligning with the IUCN definition of regeneration: inclusive, justice-oriented, and rooted in conservation over substitution of blue natural capital[20] (e.g., Biotechnology, marine CDR).
- **Low-impact:**
  Interacts with seabed or marine zones, but potentially low ecological footprint if responsibly managed (e.g., offshore geothermal, geological hydrogen).
- **Enabling platform technologies:**
  Tools and systems that support data collection, monitoring, and deployment (e.g., ocean transport, ocean communication technology, ocean observation, sampling, and analytics).
- **Extractive:**
  Relies on resource removal and causes large-scale ecosystem disruption (e.g., deep-sea mining, offshore oil & gas, bottom trawling).

The matrix visualizes how deep ocean sectors compare in technological readiness, market maturity, and scaling trajectory.

- Established extractive sectors such as offshore oil and gas and bottom trawling dominate in total addressable market (TAM) and market maturity but offer limited regenerative value. Deep-sea mining remains low on readiness, market maturity, and TAM, with slower projected scaling.
- Among regenerative sectors, marine biotechnology leads in both readiness and market potential, while geothermal, geological hydrogen, and marine CDR are earlier-stage but positioned for faster market-driven growth.
- Enabling platform technologies show higher technological readiness and increasing relevance as cross-sector enablers. They are not a primary focus of this report, as they do not represent standalone markets or deliver direct regenerative outcomes. However, they remain critical enablers of deep ocean science, monitoring, and responsible industry deployment by reducing uncertainty, supporting measurement, reporting, and verification (MRV), and lowering the cost of entry for emerging regenerative models.



This comparative assessment informed the selection of marine biotechnology, geothermal and geological hydrogen, and marine CDR as focus areas for further analysis, based on their potential to advance climate mitigation, ocean regeneration, and the development of investable markets aligned with equitable stewardship.

Context on extractive baselines[2]:

- **Offshore oil & gas:**
  Dominates the ocean economy, reaching USD 987 billion in 2020 and accounting for 33% of global ocean economy. While providing energy and jobs, the sector contributes significantly to emissions and marine disruption. Decommissioning has become a regulatory focus, especially in the Gulf of Mexico, where 150—250 rigs are dismantled annually.
- **Bottom trawling:**
  Accounts for ~25% of global marine catch, operating almost entirely within EEZs. It rivals global artisanal fisheries in total volume but is vastly more destructive. Recovery of trawled ecosystems, especially in deep waters, can take decades to centuries, prompting bans in countries like Costa Rica and calls for stricter regulation globally.

1.3 Why now? Acceleration of international and national initiatives

A wave of international and national initiatives is reshaping the governance of marine genetic resources (MGRs), digital sequence information (DSI), and deep ocean innovation. The adoption of the BBNJ Agreement, evolving frameworks under the CBD and Nagoya Protocol, and forward-leaning national strategies, from ABS systems in Southeast Asia to bio-data infrastructure in the United States, signal a shift toward greater equity, transparency, and scientific cooperation.

a. International landscape

At the global level, landmark frameworks such as the BBNJ Agreement, the CBD, and the Nagoya Protocol are redefining governance of the deep ocean by introducing new rules on marine biodiversity, benefit-sharing, and environmental safeguards. These agreements represent growing momentum to formalize stewardship of deep ocean resources and to align scientific discovery with equitable access and use.

Several foundational regimes shape today's international ocean governance landscape. The International Seabed Authority (ISA), under UNCLOS, oversees activities in the seabed of Areas Beyond National Jurisdiction (ABNJ), though its mandate is limited to mineral resources. The Convention on Biological Diversity (CBD) and its Nagoya Protocol govern access and benefit-sharing (ABS) of genetic resources within national jurisdictions, requiring Prior Informed Consent (PIC) and Mutually Agreed Terms (MAT). However, they do not currently cover marine genetic resources (MGRs) in ABNJ or digital sequence information (DSI), leaving critical governance gaps[26 27].

The adoption of the Biodiversity Beyond National Jurisdiction (BBNJ) Agreement aims to close those gaps. The treaty introduces the first global framework for conservation and sustainable use of marine biodiversity in ABNJ. Over 100 countries have signed it, though a critical mass of ratifications is still needed for it to enter into force. It emphasizes equity, science-based decision-making, and coordination with existing regimes such as UNCLOS, ISA, and sectoral bodies. Key implementation pillars include marine protected areas, environmental assessments, capacity building, and benefit-sharing[28 29].

To support fair use of MGRs, the BBNJ Agreement also proposes tools for tracking and sharing benefits, including open-access science mechanisms and evolving monetary models. One such model, the CBD's proposed "Cali Fund," would collect a percentage of revenues or profits from large DSI users, channelling proceeds toward biodiversity conservation and equitable access[30].

The UN Decade of Ocean Science further reinforces this shift by promoting data systems, capacity building, and long-term alignment between marine research, conservation, and equity goals.

See **Annex 5.** for mapping of the highlighted international instruments for deep ocean governance and benefit sharing.

b. National-level initiatives

Countries are advancing diverse strategies to govern marine genetic resources (MGRs), digital sequence information (DSI), and ocean innovation. Pioneers such as the United States, Australia, and Costa Rica are leveraging policy tools, ABS frameworks, and data infrastructure to shape marine biotechnology and biodiversity governance in line with domestic priorities and emerging bioeconomy ambitions.


Photo by OceanX

In the United States, biotechnology has been identified as a strategic priority. The National Security Commission on Emerging Biotechnology and a recent U.S. Senate report emphasize AI-driven biological research and the need for national bio-data infrastructure to safeguard sensitive databases and drive innovation. The alignment of these recommendations with current policy remains evolving.

In Southeast Asia, countries like Malaysia, Indonesia, and the Philippines operate relatively mature ABS systems, shaped by the Nagoya Protocol and national biodiversity plans. Malaysia's 2017 ABS Act, Indonesia's 2018 Decree, and the Philippines' royalty-sharing and GEF-backed ABS Project reflect growing regional commitment to equitable access and benefit-sharing[26].

Australia combines federal and state-level ABS regulations, particularly where traditional knowledge is involved. It is active in global discussions on DSI and Indigenous knowledge protections and is integrating ABS into its biodiversity finance and innovation strategies, particularly as the potential host of COP31[31 32].

France and Costa Rica, co-hosts of the UNOC3, are similarly active. France is advancing domestic ABS legislation while advocating for fair benefit-sharing in ABNJ. Costa Rica, known for its pioneering national ABS frameworks and early bioprospecting models, is advancing its ABS agenda through innovative partnerships, capacity-building, and promoting digital biodiversity databases aligned with fair and equitable benefit-sharing principles.


Photo by OceanX

Chapter II. Readiness and roadblock assessment of deep ocean emerging sectors

Chapter summary: Biotechnology, energy (geothermal and geological hydrogen), and marine CDR, selected for their potential to advance climate mitigation, biodiversity protection, and inclusive development, are among the most promising industries to enable a regenerative deep ocean economy. Yet each faces critical inflection points. While biotechnology has advanced to market-ready applications, ocean-based energy and marine CDR face persistent gaps in R&D, infrastructure, MRV, and risk sharing mechanisms. Research and science remain essential to their development, underpinning technological validation, de-risking, and the creation of credible standards and methodologies needed to scale. Platform technologies, such as data, transport, and communications remain essential enablers. Mapping the maturity, constraints, and interdependencies across these sectors reveals where targeted support can turn bottlenecks into breakthroughs.

2.1 Priority sectors' maturity and technology readiness assessment

This chapter assesses the impact rationale, maturity, market potential, and remaining roadblocks for three regenerative deep ocean sectors: marine biotechnology, offshore energy (geothermal and geological hydrogen), and marine carbon dioxide removal (mCDR). Collectively, they could contribute an estimated $11 trillion in cumulative market potential over the next 40 years. Realizing this opportunity will require addressing the technical, regulatory, and financing challenges mapped in this chapter.

a. Biotechnology

Biotechnology has already reached its technological tipping point, driven by exponential advances in sequencing, metagenomics, and synthetic biology. DNA sequencing costs have dropped from ~$10,000 per megabase in 2001 to just $0.01 today, enabling faster, AI-assisted biodiscovery from deep-sea genomes to commercial products. With a projected cumulative market of $440 billion over the next 40 years, marine biotechnology stands out as the most mature and near-term investable sector in the regenerative ocean economy. Yet without stronger data infrastructure, governance, and benefit-sharing mechanisms, much of its potential risks remaining stranded in research labs.

i. Impact rationale

Biotechnology represents the most mature and investable pathway for non-extractive value creation from the deep ocean. By unlocking the untapped genetic resources of deep-sea extremophiles and microbiomes, marine biotechnology can deliver transformative benefits across health, food security, and climate resilience[19 33 34 35].

→ **Climate, health and industrial impact:** Marine biotechnology harnesses unique enzymes and compounds from deep-sea organisms, found in extreme environments like hydrothermal vents, for use in next-generation pharmaceuticals, food production, fuels, and materials[36]. See **Annex 1.** for illustrative examples of marine biotechnology products and use cases across industries; and **Annex 2.** for a mapping of key marine biodiversity sources and their potential applications.

→ **Strategic economic opportunity for biodiversity-rich nations:** Bioprospecting and biological IP from deep-sea biodiversity could become a sovereign asset, positioning countries with rich marine ecosystems capture more economic value from agriculture, health, and materials' global supply chains. The global bioeconomy is projected to reach $7 trillion by 2030[37], creating inclusive economic opportunities for Global South nations.

→ **Linking discovery to protection:** Bioprospecting typically requires only small sampling and, when guided by ABS principles and open data-sharing, can close knowledge gaps and support marine conservation. When paired with ecosystem protections and benefit-sharing mechanisms, it can drive both scientific progress and local stewardship. It also has the potential to generate high-quality jobs in participating countries and contribute to 30x30 goals by providing an additional income stream to marine protected areas.

ii. Pipeline maturity and TRL

Marine biotechnologies have already reached technological tipping points, supported by dramatic declines in DNA sequencing costs, from approximately $10,000 per megabase in 2001 to around $0.01 in 2020. This cost trajectory has enabled high-throughput biodiversity exploration and accelerated biodiscovery pipelines[29].

Recent advances in high-throughput sequencing (HTS), metagenomics, metabolomics, bioactivity screening, and synthetic biology tools have significantly improved the efficiency of turning marine samples into commercial products[15] (See **Annex 6.** for an overview of biodiscovery pipelines and methodologies in marine biotechnology). Sequencing technology is increasingly accessible through low-CAPEX micro-labs, which allow on-site data collection and reduce sample degradation risks, lowering barriers for in-situ exploration of remote deep-sea ecosystems[39].

Several leading companies, including Basecamp Research, PharmaMar, Illumina, Givaudan, DSM-Firmenich, Novozymes, and AstraZeneca, are advancing marine biotechnology pipelines in pharmaceuticals, agriculture, personal care, and industrial applications. These companies are leveraging innovations from AI-driven discovery and sequence-based screening to pursue non-extractive, data-based bioprospecting models[29]. See **Annex 7.** for examples of company-led pipeline activities and innovations in marine biotechnology; and **Annex 8.** for a focused case study on Basecamp Research.

To date, around 20 deep-sea-derived drugs have been commercialized, including Cytarabine

(Ara-C), a widely used leukemia treatment sourced from a deep-sea sponge[33]. There are also a few enzymes from Antarctic organisms or isolated from ocean environments that have found notable commercial success, for example, Candida antarctica lipase B and thermostable enzymes from Pyrococcus furiosus, sourced from geothermal marine sediments[38].

Intellectual property strategies in the sector are also evolving. There is a shift from traditional compound-based patents to sequence-based licensing, supported by the growth of genomic libraries and biodiversity data assets. Countries such as France, Brazil, and the United States (see NSCEB Section 4.1 on genetic data sovereignty) are developing national-scale biodiversity data repositories to support domestic innovation and protect regulatory sovereignty[33].

iii. Link between AI model training and deep ocean ecosystems

Terrestrial species dominate public genomic datasets, with over 200 million proteins cataloged, while marine and deep-sea organisms remain severely underrepresented, limiting the diversity of training data for AI-driven discovery in pharmaceuticals, enzymes, biofuels, and sustainable materials[33 39].

Advances in machine learning and computational biology are prompting a shift toward proprietary, domain-specific biological datasets. Companies are racing to build unique data assets to accelerate discovery, secure intellectual property, and tap into the "Internet of Life", a diverse biological data universe where deep-sea extremophiles may unlock breakthrough innovations and competitive advantages[33 40].

Simultaneously, AI capabilities are evolving rapidly, with synthetic biology models anticipated to soon operate with significantly lower data input requirements, shifting data bottlenecks and further elevating the importance of effective ABS frameworks. Advances in bioinformatics, molecular provenance tools, and digital sequencing are improving traceability, making it increasingly possible to link synthetic biology drugs to their original nature-based compounds or genetic sequences when the source is known and documented.

iv. Market size (total addressable market ('TAM')), growth, and tipping point assessment

The global market for marine biotechnology products and processes was valued at \$3.93 billion in 2017 and is projected to grow to \$8.74 billion by 2026, with a compound annual growth rate (CAGR) of 9.3%[15]. If this growth trajectory (~10% CAGR) continues, the cumulative market size is expected to reach approximately \$440 billion over the next 40 years (See **Annex 9.** for detailed calculation).

Countries like Saudi Arabia and New Zealand are well positioned to benefit from marine biotechnology. In contrast, small island developing states such as Nauru and Kiribati may face structural challenges in realizing direct benefits, due to limited research capacity, industrial infrastructure, and access to global markets[41]. However, emerging innovations such as portable micro-labs and the commoditization of sampling and sequencing technologies are lowering technical barriers and enabling greater local participation. Increasingly, samples no longer need to be exported to advanced biotech hubs; with appropriate training, a larger share of the bioprospecting value chain can remain in-country.

v. Remaining roadblock and challenges

→ Technical hurdles: High R&D costs and long commercialization timelines remain major barriers for end product design and production, especially without strong funding, verification systems, and dedicated platforms for scaled research. Commercial-scale applications still depend on wet-lab validation and complex bioprocessing, which are particularly challenging because each deep-sea microbial strain often requires unique growth conditions and behaves differently in producing useful compounds[15 39].

Deep-sea exploration is costly and underfunded, with most countries lacking mechanisms to support regular biodiversity missions. Access to vessels and submersibles is limited, delaying research and innovation. High baseline uncertainty, driven by seasonal and climate variability, adds risk, while sampling remains logistically difficult and expensive. Most funding currently comes from the military sector[33 35 42 43].

Photo by Ramona Osche / Ocean Image Bank

These hurdles are compounded by systemic gaps. AI models struggle with sparse, non-diverse training data, raising doubts about marine biotech's reliability and increasing environmental costs. There is still no integrated platform connecting upstream sampling with downstream use across biotech, AI, materials, and food sectors, leaving many discoveries stranded in academic literature[33].

Coordination across the ecosystem remains weak. Links between academia, industry, and finance are underdeveloped, with few spinouts and limited technology deployment, which slows the sector's ability to scale.

→ **Regulatory gaps:** Governance frameworks around marine genetic resources (MGRs) and digital sequence information (DSI) remain inconsistent and fragmented. Most open-access DSI databases lack traceability, limiting compliance with benefit-sharing protocols. ABS frameworks vary widely: some countries have not ratified the Nagoya Protocol, and others struggle with enforcement, leaving early-stage access under-regulated. For example, Brazil's ABS regime applies only to samples collected in Brazilian territorial waters; for Antarctic or non-territorial samples, the ABS regime applies only after samples are modified in the lab (e.g., cultured), not at point of collection[38]. Conflicting obligations across Nagoya, CBD, and BBNJ increase compliance friction for researchers and private firms alike.

Small institutions and Global South actors face high legal and administrative barriers to participate in marine biotech. While the Global North supports open-access models, many biodiversity-rich countries are concerned about biopiracy and the unregulated monetization of genetic resources.

To date, no marine-derived drugs have generated royalties for coastal states or supported ecosystem stewardship[33]. Without stronger feedback loops between innovation and conservation, marine biotech risks advancing without safeguarding its ecological foundations.

→ **Market/funding challenges:** Biotechnology's high capital intensity and slow time-to-revenue make it difficult to align with conventional investment mandates. The development timelines and risk profiles of marine biotech ventures often fall outside the scope of typical venture capital and infrastructure investors. In addition, revenue-sharing models with coastal states, especially within Exclusive Economic Zones (EEZs), rarely align with current impact investing frameworks, leaving marine biotech stranded between public research and commercial finance[35].

b. Energy (geothermal and geological hydrogen)

Offshore geothermal and geological hydrogen represent early-stage conceptual clean energy prospects with long-term potential but remain far from commercial deployment. Geothermal systems are progressing through two distinct pathways, from TRL 4 to 9, with limited piloting and high infrastructure costs; geological hydrogen lags behind, with offshore production still conceptual despite promising natural hydrogen fluxes at sites like the West Iberia margin. Both rely heavily on deep-sea exploration for accurate resource mapping and face mounting competition from rapidly declining costs of land-based renewables. While geothermal could theoretically reach a $700 billion cumulative market over 40 years, realization will depend on overcoming steep technical, regulatory, and financing barriers.

i. Impact rationale

Geothermal and geological hydrogen offer emerging deep ocean energy solutions that provide firm, low-emission power while strengthening energy sovereignty and industrial diversification for seabed-rich nations[44].

→ **Climate, energy security, and industrial impact:** Innovations in low-impact drilling, subsea exchangers, and modular systems could enable co-production of green hydrogen, ammonia, and freshwater, while supporting or maintaining coastal jobs in marine energy. See **Annex 3**. for a mapping of offshore geothermal's co-benefits and responsible development pathways.

→ **Strategic economic opportunity for seabed-rich nations:** Countries with access to hydrothermal fields, subduction zones, and passive margins (such as those along mid-ocean ridges) could treat these as strategic clean energy reserves.

→ **Linking innovation to stewardship:** The regenerative potential of offshore geothermal and geological hydrogen is limited, but projects can still support deep ocean stewardship by integrating environmental monitoring and open-access data to improve knowledge and inform equitable governance.

ii. Pipeline maturity and TRL

Offshore geothermal energy is progressing along two main technology pathways, with systems ranging from TRL 4—9 depending on the technology. Several countries, including Iceland[44], Indonesia, Norway, and New Zealand, are conducting feasibility studies, proof-of-concept trials, and pilot deployments (see **Annex 10.** and **Annex 11.** for detailed examples).

→ **Heat exchange with turbine systems (TRL 4-6):** This approach uses heat exchange from high-temperature rock formations to drive turbines and generate electricity. While mature onshore, adaptation to offshore environments presents no major technological barriers with high scaling potential. The potential market includes Small Island Developing States (SIDS) with high energy import costs and limited space for solar or wind. Offshore rigs could be retrofitted, though borehole size and location mismatches may require design adjustments.

Key enablers for the technology include clarifying permitting pathways in priority Exclusive Economic Zones (EEZs), mapping hot rock formations to estimate energy potential (a process that currently costs around $50,000 of ship time per day but is expected to become cheaper with advances in robotics and MRV technology) and building First-of-a-Kind (FOAK) demonstration plants, such as those modeled on Fervo Energy's onshore geothermal projects.

→ **Small solid-state thermoelectric units (TRL 8-9):** These compact systems use temperature gradients to generate electricity via the Seebeck effect, with materials like bismuth telluride. Successfully piloted by the U.S. Office of Naval Research, they are well-suited for autonomous and off-grid applications. Advantages include low maintenance, small form factor, and ease of deployment in remote marine settings.

However, low conversion efficiency (5—8%) and limited capacity (typically in the kilowatt-hour range, with an upper limit around 10 MWh) mean they are not viable for utility-scale power. Use cases include powering marine protected area surveillance, underwater robotics, and long-duration ocean sensors. (See **Annex 12.** for a detailed overview of solid-state thermoelectric units).

Geological hydrogen is at an earlier development stage, with current TRLs between 4 and 6. Most activity is land-based, focused on exploratory drilling and feasibility studies. No commercial offshore production exists, and the technology remains largely conceptual for marine settings.

Research into serpentinization zones, such as the West Iberia margin and Lost City hydrothermal field, shows high natural hydrogen fluxes, with early drilling samples reporting concentrations of 120–300 mmol/kg (see **Annex 13.** on case study of West Iberia margin and Lost City hydrothermal field). These environments are drawing commercial interest, especially around continental shelf olivine deposits and hydrothermal vent systems rich in hydrogen sulfide. However, no extractable offshore reserves have been confirmed, and offshore infrastructure is still undeveloped.

More than 50 companies are exploring geological hydrogen globally, but most are focused on IP development and terrestrial applications. Past efforts like Hawaii's NELHA project, which explored hydrogen from OTEC and seawater electrolysis, were constrained by cost and technical complexity[45].

iii. Market size (TAM), growth, and tipping point assessment

Under conservative assumptions, offshore geothermal could generate ~$700 billion cumulatively over 40 years, based on achieving 10% (~80 GW) of IEA's projected global geothermal capacity by 2050[46] (See **Annex 9.** for detailed calculation). Hydrogen demand is projected to rise from 90 to 660 million tonnes per year by 2050. If offshore geological hydrogen proves viable, it could offer a simpler, potentially lower-cost value chain by bypassing the need for renewable electricity and carbon capture systems[47].

iv. Remaining roadblocks and challenges

→ **Technical hurdles:** Geothermal turbine systems require costly subsea infrastructure and cabling (~$500,000/km). FOAK plants demand large capital outlays and long lead times. Solid-state units are less capital-intensive but unsuitable for large-scale generation. For geological hydrogen, technical challenges include the absence of offshore wells, risks like hydrogen embrittlement, and lack of tested well designs or transport infrastructure.

Despite theoretical promise, both deep-sea geothermal and geological hydrogen remain far from commercial viability. Deep-sea geothermal energy has yet to benefit from a comprehensive techno-economic analysis[45], and each of its two major technology streams presents distinct technical challenges. Geothermal turbine systems require costly subsea infrastructure and cabling (~$500,000/km). Solid-state units are less capital-intensive but unsuitable for large-scale generation. For geological hydrogen, technical challenges include the absence of offshore wells, risks such as hydrogen embrittlement, and lack of tested well designs or transport infrastructure.

Competitive pressure is also rising: in just two years, solar and battery prices have fallen 66% and 58% respectively, widening the cost gap for deep-sea alternatives[48].

→ **Regulatory gaps:** Permitting frameworks for offshore geothermal and hydrogen remain undefined in most jurisdictions. For geothermal energy, regulatory clarity is lacking in both Exclusive Economic Zones (EEZs) and Areas Beyond National Jurisdiction (ABNJ). Existing seabed and mining codes have not been adapted to address these technologies.

In Southeast Asia, no permitting systems are currently in place for offshore deployment. Australia is one of the few countries with a national hydrogen licensing framework, though it applies only to onshore activities.

→ **Market/funding challenges:** Both sectors lack dedicated funding mechanisms and fall between conventional categories (innovation, infrastructure, and exploration) resulting in low investor familiarity and few project finance precedents. Their early-stage risk profile and capital intensity make them less competitive against mature land-based renewables[41].

c. Marine CDR

Marine CDR remains highly experimental, with technologies spanning TRL 1–6 and no commercial-scale deployments to date. Nature-based and hybrid methods are more advanced, but even well-funded efforts, such as Running Tide's, have collapsed due to weak demand and lack of measurable impact. Verification remains a core barrier: effectiveness may take 10–20 years to confirm, while MRV standards are still evolving. Though the sector could reach a cumulative market value of $10 trillion under optimistic scenarios, scaling will require overcoming deep scientific uncertainty, regulatory ambiguity, and severe funding shortfalls.

i. Impact rationale

Marine Carbon Dioxide Removal (mCDR) uses chemical, biological, and physical methods to enhance the ocean's natural carbon cycle and is being explored as an early-stage climate solution[49].

→ **Climate, biodiversity, and adaptation impact:** mCDR approaches aim to amplify the ocean's natural role in the global carbon cycle, offering a potential pathway to remove atmospheric CO_2 while supporting marine ecosystem functions. Indicative sequestration potentials include:

a. **Ocean Alkalinity Enhancement (OAE):** 1–15+ $GtCO_2$/year.
b. **Artificial upwelling/downwelling:** Negligible current scale, and the potential uncertain.
c. **Enhanced fertilization:** >1 $GtCO_2$/year (depending on system design and species).
d. **Deep-sea biomass or CO_2 storage:** ~1.3 tCO_2/year per km^2 of seaweed farmed and sunk. However, the seaweed sinking method remains scientifically and ethically contested, as there is limited evidence that it effectively removes atmospheric CO_2.

→ **Strategic economic opportunity for coastal and island nations:** mCDR offers emerging opportunities for countries to participate in carbon removal and ecosystem service markets. While most methods remain in research or pilot stages, some (e.g., shallow-water OAE) could be integrated into broader blue economy strategies if responsibly developed[49].

→ **Potential regenerative contribution:** In theory, mCDR approaches can support regeneration by improving ocean chemistry and biodiversity. For instance, OAE may help rebalance pH and reduce anoxic zones; fertilization could stimulate marine food webs; and seaweed cultivation may create habitat structures[34, 50].

Cautionary considerations: Despite potential benefits, large-scale mCDR may carry significant ecological risks. For example, Seaweed sinking remains unproven for atmospheric CO_2 removal and may cause oxygen depletion, disturb ecosystems, or release methane[51, 52, 53]. See **Annex 4**. for detailed descriptions of each mCDR approach, associated methods, co-benefits, and impact considerations.

ii. Pipeline maturity and TRL

Marine CDR technologies span TRL 1–6, with most approaches still in lab or pilot testing stages and no commercial-scale deployments to date[45, 49, 54].

→ Intermediate-maturity pathways include deep-sea biomass burial and subseafloor carbon storage, which have undergone limited offshore piloting. Methodologies for crediting seaweed burial are under review by carbon registries like Verra, though concerns remain around permanence, environmental risk, and MRV quality.

→ Lower-maturity engineered solutions include ocean alkalinity enhancement (OAE), artificial upwelling/downwelling, and enhanced fertilization. OAE has been tested in small-scale settings, but not yet in open-ocean conditions. Enhanced fertilization has been lab-modeled but lacks field validation, while upwelling/downwelling remain theoretical.

The sector's intellectual property (IP) landscape is also thin, with few offshore-specific patents. Most firms remain in feasibility or demonstration phases, underscoring the need for coordinated public-private investment to build technical readiness and safeguards. Running Tide, which raised millions to sell seaweed-sinking credits, collapsed after failing to generate demand or measurable impact[55].

iii. Market size (TAM), growth, and tipping point assessment

Marine CDR could reach up to $10 trillion in cumulative market value over the next 40 years, based on an optimistic scenario where the sector grows to $500 billion annually by 2050, followed by a sustained plateau (see **Annex 9.** for detailed calculation).

Key tipping points include accelerating real-world demonstrations, establishing robust environmental safeguards, and unlocking blended capital to support early-stage deployment and learning[50].

iv. Remaining roadblocks and challenges

→ **Technical hurdles:** Most mCDR methods remain unproven at scale and difficult to validate. Ocean variability and slow carbon cycling mean effectiveness may take 10—20 years to confirm, with some purchasing only partial credits (e.g., 70% of projected removals) up front to account for uncertainty in long-term verification. At the same time, deployment timelines are tight. 2026 is viewed as a critical milestone: real-world pilots need to be launched soon to generate sufficient empirical data by 2030, in time to inform scale-up decisions[5].

MRV systems remain a core weakness: standards are underdeveloped, protocols vary across methods, and crediting methodologies are still evolving. Small discrepancies in model assumptions can lead to large discrepancies in projected CO_2 removal outcomes. There is also a pressing need for independent evaluations of whether mCDR projects are truly delivering net carbon removal benefits[45, 56].

Physical infrastructure is limited, and most startups must self-finance development. Unlike land-based CDR, marine CDR lacks clusters, pipelines, and logistics systems. Many also lack viable commercial models for collection, processing, and monetization.

→ **Regulatory gaps:** Regulatory environment for mCDR remains highly fragmented and underdeveloped. In both EEZs and ABNJ, jurisdictional authority remains unresolved, leaving uncertainty over how and under what conditions mCDR activities may proceed[50]. For example, the OAE approach is classified as 'ocean dumping' under the London Protocol unless recognized as scientific research[56].

Further, past rogue experiments, such as the Russ George iron fertilization case, where iron was dumped off Canada's west coast in 2012 without clear scientific or regulatory oversight, have damaged public and scientific perceptions of mCDR and triggered calls for stricter governance[50].

Without regulatory clarity, credible offtake agreements are difficult to establish. Buyers face legal and reputational risks in the absence of compliance frameworks or permitting systems, deterring long-term investment[50].

→ **Market and funding challenges:** mCDR faces severe capital constraints. Despite its theoretical importance to global carbon budgets, mCDR currently receives less than 10% of total climate-tech investment, underscoring the need for accelerated field trials and scalable demonstration efforts.

Funding has largely come from research grants, early-stage VC, and voluntary carbon markets (VCMs)[50]. While VCMs reached $2 billion in 2021 and may grow to $10—40 billion by 2030, ocean-based credit demand remains low due to MRV concerns. Even major buyers like Amazon, which has committed over $500 million to carbon credit purchases, have only made few ocean-based investments to date.

Emerging models like advance market commitments (AMCs) offer some promise. Examples such as Stripe's tiered pre-purchase model, ranging from $1,000 to $100 per ton, demonstrate how buyers can help de-risk innovation and anchor price trajectories ahead of commercial maturity[45].

National efforts may also play a catalytic role. Some countries, such as Saudi Arabia, are developing carbon market readiness strategies that include digital MRV and jurisdictional pilots. These initiatives could provide the foundation for more structured mCDR investment in the near term. (See **Annex 14.** for an update on Saudi Arabia's carbon market readiness.)

Given these challenges, marine CDR may benefit from being reframed not solely as a carbon solution, but as part of a broader regenerative ocean economy. This shift could unlock wider infrastructure investments and diversified funding tied to ecological, social, and climate co-benefits.

2.2 Platforms technologies

From carbon monitoring to biodiversity sampling, the future of deep ocean industries depends on the platforms that make exploration possible. This section examines the underlying technologies (observation systems, autonomous vehicles, and subsea communications) that enable data collection, access, and coordination at depth. While not end markets themselves, these "picks and shovels" are rapidly maturing, with a significantly larger and more mature total addressable market than the three emerging sectors discussed earlier (biotechnology, geothermal and geological hydrogen, and marine CDR), and with established commercial use cases.

a. Ocean observation, sampling, and analytics[57]

Ocean observation, sampling, and analytics systems are rapidly advancing, with most core components operating at TRL 7–9. While tools are commercially available, adoption remains fragmented, and integration across use cases and geographies is limited. Key tipping points include reducing cost barriers, expanding public–private data infrastructure, and enabling cross-sector data interoperability, especially to support Global South stakeholders.

i. **Pipeline maturity and TRL**
Most core ocean observation and sampling platforms, such as moored systems, seabed landers, and deep-sea cables, are now equipped with advanced IoT sensors and telemetry and have reached TRL 7–9. These systems are commercially deployed across conservation, enforcement, and ESG monitoring. UAVs, USVs, and UUVs are also advancing in autonomy, durability, and modular design, enabling longer and more versatile missions. Open-source platforms (e.g., OpenSC) and commercial providers (e.g., Planet) are helping expand uptake across both public and private sectors.

ii. **Market size (TAM), growth, and tipping point assessment**
In the U.S. alone, the ocean observation and forecasting market reached $7 billion in 2018. Globally, maritime big data is projected to grow at a 12.8% CAGR through 2030, driven by rising demand across fisheries, climate science, and biodiversity tracking. Key application areas include mineral mapping, marine bioprospecting, biodiversity monitoring, marine CDR MRV, and offshore energy surveying (including offshore wind). Tipping points for adoption include: (1) cross-sector data integration, (2) cost reduction to improve access in the Global South, and (3) expanded, interoperable public–private data infrastructure.

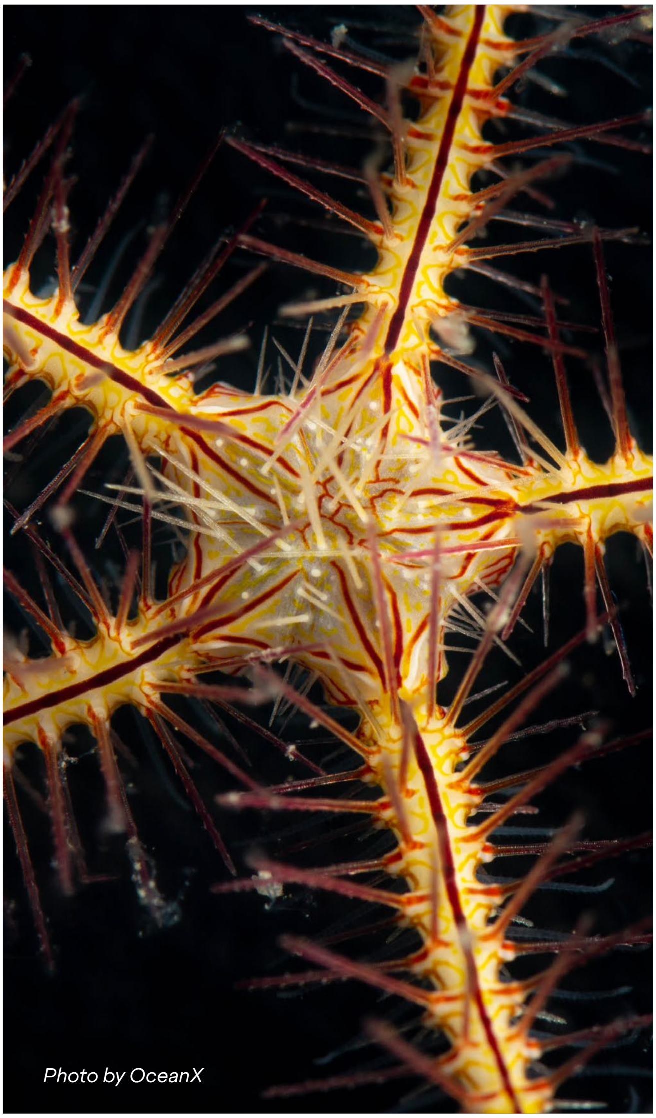


Photo by OceanX

b. Ocean transportation

Ocean transport platforms, including AUVs, ROVs, and hybrid submersibles, are foundational to accessing deep ocean environments. These systems are widely used in industry and science (TRL 7–9) and are beginning to serve regenerative ocean sectors through enhanced autonomy, modular payloads, and compatibility with tools like eDNA samplers and chemical sensors. However, high costs, limited access to advanced fleets, and infrastructure gaps constrain broader adoption, especially for Global South actors.

i. Pipeline maturity and TRL

Autonomous Underwater Vehicles (AUVs), Remotely Operated Vehicles (ROVs), and hybrid submersibles are operating at TRL 7–9, with widespread use in scientific and industrial missions. Newer models are improving in autonomy, energy efficiency, and modular payload design, enabling multipurpose, extended missions. Advances in compact payloads (e.g., eDNA samplers, chemical sensors, and robotic manipulators) are expanding applications in biodiversity monitoring and low-impact exploration.

ii. Market size (TAM), growth, and tipping point assessment

The offshore AUV and ROV market was valued at $4.5 billion in 2023 and is projected to reach $12.9 billion by 2030[58] [59]. Key end-use areas include defense and security applications, deep-sea mapping, marine bioprospecting, biodiversity assessment, CDR deployment and MRV, and offshore clean energy exploration (e.g., geothermal wells and hydrogen scouting). Broader adoption will depend on: (1) scalable real-time control to support deep operations, (2) modular designs for multi-mission use (3) significant cost reductions to expand access for Global South institutions and non-commercial users. In parallel, enabling precise subsea sampling and inspection with agile autonomous vehicles would be a major value unlock, representing the most viable pathway to decouple deep sea access from surface ships and scale deep ocean exploration and monitoring.

c. Ocean communication technology

Subsea communication technologies, spanning cabled fiber, acoustic modems, and emerging optical links, enable real-time data transfer, coordination, and monitoring in deep ocean settings. While cabled systems are fully mature (TRL 9), wireless alternatives remain constrained by bandwidth, range, and energy use. Unlocking their full potential will require advances in acoustic bandwidth, efficient mesh relays, and open standards that enable seamless integration across ocean platforms.

i. Pipeline maturity and TRL

Cabled fiber-optic and telemetry systems are fully mature (TRL 9) and widely used on offshore platforms and deep-sea observatories. Acoustic systems, used for tracking AUVs and connecting subsea sensors, are at TRL 6–8 but remain limited by range and bandwidth. Optical communication systems are emerging (TRL 5–7), offering high data rates over short distances but performing poorly in turbid water. Autonomous relays and mesh network nodes are under development (TRL 4–6) to support longer-range, persistent operations.

ii. Market size (TAM), growth, and tipping point assessment

The global subsea communications market was valued at ~$4 billion in 2024 and is projected to reach $10 billion by 2033[60] [61]. Key applications include data transmission and equipment control for bioprospecting, CDR MRV, deep-sea exploration, and offshore energy operations. Critical tipping points include: (1) deployment of high-bandwidth acoustic and hybrid systems, (2) development of low-energy relays and seabed nodes for extended missions, and (3) standardization of open protocols to ensure cross-platform and cross-sector integration.


Photo by Lorenzo Mittiga / Ocean Image Bank

Chapter III. Proposition of innovative financial instruments to bolster shortlisted regenerative industries

Chapter summary: Finance rarely leads in frontier markets, it follows demonstration, not just potential. In the deep ocean, early proof points are expensive, high-risk, and fragmented across sectors, creating persistent funding gaps at mid-TRL and pre-commercial stages. This chapter proposes three flagship financial instruments to unlock innovation tipping points: a National Nature Capital Fund to assert sovereignty over marine biodiversity and monetize digital sequence data; a Deep Ocean Deep Tech Cluster to consolidate infrastructure and accelerate cross-sector commercialization; and a FOAK Project Finance Facility to bridge the capital gap for first-of-a-kind marine energy deployments through milestone-tied loans. Together, these instruments aim to de-risk investment, align public and private capital, and establish a scalable architecture for the regenerative ocean economy.

3.1 A small and fragmented financing landscape

Despite growing attention to deep ocean innovation, the current financing landscape remains fragmented and poorly coordinated, with critical gaps at early and mid-TRL stages. Private R&D, venture capital, and sovereign funds are active but operate in silos, limiting pipeline development and market scaling. Addressing these gaps will require more deliberate coordination of public and private capital streams and tailored finance mechanisms for each sector.

a. Mapping current actors: academia & research centers, development banks, venture capital, sovereign donors, corporate R&D

The deep ocean financing landscape remains fragmented and early-stage, with most capital flowing through corporate R&D, philanthropy, and niche venture funds. Marine biotech is primarily driven by internal investment from large firms, while mCDR relies heavily on philanthropy and climate-aligned VCs, with only a few early corporate pre-purchase commitments. Public investment in geological hydrogen is growing and deep-sea geothermal remains virtually absent from funding pipelines despite its technical maturity.

i. Biotechnology

Marine biotechnology is primarily funded by corporate research and development. Leading companies such as Basecamp Research, Illumina, PharmaMar, DSM-Firmenich, Givaudan, Novozymes, and AstraZeneca support their own sequencing, discovery, and proprietary data systems. Despite this activity, marine-derived products still represent only a small share, typically under 5% of these companies' overall portfolios[35 29 39].

Beyond corporate actors, philanthropic foundations (e.g., Minderoo Foundation[62]) are beginning to back marine biotech projects.

ii. Energy (geothermal and geological hydrogen)

Geological hydrogen is attracting growing interest from public and private sectors, though most current capital remains focused on green and land-based hydrogen. Redirecting a portion of this investment toward geological hydrogen, especially in marine contexts, could help accelerate technical progress and infrastructure development[47].

Public sector activity is emerging across several regions. Major hydrogen initiatives in the U.S., EU, and Asia have begun supporting geological hydrogen R&D, with countries like France, Japan, and South Australia introducing exploration licenses or dedicated frameworks. Southeast Asia has also entered the space, led by Singapore and Sarawak[47].

On the private side, startups have secured early-stage financing, while energy majors such as BP and Rio Tinto are exploring geological hydrogen as part of broader decarbonization strategies. Sovereign wealth funds and multilateral institutions may play a catalytic role as the sector matures and aligns with development or climate goals[47].

See **Annex 15.** for a detailed mapping of public programs, private investments, and institutional initiatives supporting geological hydrogen.

In contrast, deep-sea geothermal remains largely overlooked by both public and private portfolios. Despite its technical maturity in defense contexts, it lacks dedicated innovation hubs or project finance vehicles to support marine deployment.

iii. Marine CDR

The funding landscape for mCDR is nascent and highly fragmented. Philanthropic actors, notably the Grantham Foundation, have provided catalytic support for early research and pilot testing[50].

Specialized early investors, including Propeller VC, Twynam, and Counteract, are beginning to shape the emerging mCDR investment landscape. Notable companies receiving early backing include VyCarb (Twynam), Ebb Carbon (Propeller VC), Carbon Run (Counteract), and Aquatic Labs (Counteract)[56 63 64]. Additional companies attracting early investment include Vesta, Skyology, Planetary Technologies, SeaO2 and Captura[49 45].

Corporate actors, including Chevron and ExxonMobil, have begun supporting mCDR R&D as part of broader carbon capture and offset portfolios[49]. Pre-purchase agreements from companies like Microsoft are starting to channel $20—30 million into early mCDR deployments[50].

Public-sector support is emerging. The U.S. Department of Energy's ARPA-E launched a $45 million marine CDR program, the first federal initiative dedicated to ocean-based carbon removal[45]. Impact-driven capital structures such as those being explored by Builders Vision are also experimenting with blended finance approaches to de-risk early-stage investment[50].

b. Financing gaps by TRL level and sector

Critical financing gaps persist across sectors and TRL stages, particularly in the "valley of death" between R&D and commercial deployment. Biotechnology faces mid-stage funding shortages, while marine CDR and marine energy struggle to secure capital for pilots and scale-up due to high risks and infrastructure intensity. These gaps reflect both the nascency of the sectors and the misalignment between current funding models and the unique requirements of deep ocean innovation.

i. Biotechnology

While biotechnology benefits from clearer intellectual property regimes and established commercial models, there is a persistent funding gap at the mid-stage development level. This is particularly pronounced for marine-derived compounds, synthetic biology, and non-pharmaceutical applications[41]. In many cases, biodiversity monitoring or marine exploration is funded only when linked to pharmaceutical returns, limiting investment in broader ecological or industrial applications[33].

ii. Energy (geothermal and geological hydrogen)

Energy technologies face more acute structural barriers. High capital requirements, regulatory ambiguity, and unresolved technical risks (such as hydrogen embrittlement, the lack of proven well designs, and absence of supporting infrastructure) raise development risk and delay returns. These factors make early-stage investment difficult to attract and sustain[65].

iii. Marine CDR

Marine CDR ventures frequently encounter a funding wall at TRL 6 to 8, or the so-called “valley of death.” At this stage, technologies require costly field pilots to validate performance, but remain too early for infrastructure or FOAK financing, which is typically reserved for commercial-scale demonstration plants. Both pre-seed and later-stage capital (e.g., Series B+) remain scarce, leaving few viable pathways to bridge the R&D-to-deployment gap[63 66 67].

Long-duration capital is essential in this sector. Technologies often require 10 to 20 years of piloting, verification, and regulatory navigation before becoming investable at scale. This timeline deters mainstream investors, who often seek faster returns and clearer risk signals[34 66].

As a result, marine CDR is caught in a structural funding loop: technologies cannot scale without field learning, but investors hesitate to back them without proof of scalability. This dynamic stifle experimentation, restricts innovation, and delays the emergence of commercially viable solutions.

c. Lack of coordination between public and private capital in frontier marine innovation

Public and private capital streams in deep ocean innovation remain poorly aligned, resulting in fragmented support, underfunded mid-stage pilots, and limited private sector participation. Blended finance mechanisms are rare, and enabling legislation is lagging, particularly in areas such as IP ownership, biodiversity licensing, and seabed governance. Developing countries face even greater barriers, with limited technical capacity and restricted access to catalytic capital, reinforcing global inequities in marine resource development.

Financing remains fragmented across philanthropic, public, and private channels. Institutional investors continue to view the sector as high-risk, driven by regulatory uncertainty, the early-stage nature of technologies, and a lack of proof points. These perceptions limit the entry of long-term capital and slow momentum across critical sectors[68 69 70].

Public and private capital often operate in silos. Public funding tends to support basic research and exploration, while private capital seeks near-term market returns. This misalignment leaves a persistent financing gap for mid-stage pilots, too commercial for grants, yet too risky for traditional investment. Sector-specific needs vary significantly: milestone-driven venture funding may suit marine biotechnology or ocean data systems, while project finance and concessional loans are better suited to capital-intensive infrastructure like marine carbon removal and offshore energy.

Blended finance mechanisms, critical for high-risk innovation, remain underdeveloped and poorly adapted to deep ocean sectors. These sectors often require high upfront investment in fundamental science and exploration, have long development timelines, carry high uncertainty, and offer limited near-term revenue, all of which discourage conventional financing.

Regulatory enablers are also underdeveloped. National and international legislation remains unclear in key areas such as intellectual property rights, biodiversity licensing, and seabed resource management. This lack of legal clarity hampers investment structuring, weakens investor confidence, and constrains the development of viable pipelines.

At the same time, the broader enabling environment remains weak. Technical project pipelines are thin, ESG standards are inconsistent[71 72], and few mechanisms exist to benchmark impact or risk across marine sectors. These gaps make it difficult for capital providers to evaluate performance and de-risk investment, particularly in early-stage fields like mCDR, marine biotech, and ocean-based renewables.

The challenges are even more pronounced for developing countries. Many lack the technical expertise or early-stage capital needed to co-invest in projects that leverage their own biodiversity or resource assets, reinforcing a broader inequity in access to emerging marine markets.

Few platforms exist to bridge public and private funding at scale. As a result, opportunities to structure blended finance and crowd in private capital remain largely untapped. Yet models such as the U.S. ARPA-E program show what's possible. ARPA-E's milestone-based approach, which pairs public R&D funding with private handoffs and targeted de-risking, could serve as a blueprint for mobilizing innovation finance in the deep ocean economy.

3.2 The role of concessional finance to compensate for the financing landscape's shortcomings

Concessional finance is essential to bridge the financing gaps across deep ocean sectors, absorbing risks that deter private investors. This section explores when and how concessional capital can be deployed, drawing from climate finance and blended models, while highlighting the need for more flexible, proactive, and catalytic structures. It also examines the critical roles of public development banks, philanthropic capital, and sovereign innovation funds in enabling pipeline development and long-term sector growth.

a. When and how concessional capital can de-risk frontier investments

Concessional capital can unlock innovation where private finance remains absent due to high risks, regulatory uncertainty, and unclear return pathways. It is particularly important for pilot projects, MRV system development, and underfunded R&D stages in deep ocean sectors. However, to be effective, concessional finance must be bold, flexible, and willing to anchor unconventional projects that challenge traditional investment logic.

Concessional capital is essential in sectors where early-stage risk, regulatory uncertainty, and unclear return pathways deter private finance, conditions that are prevalent across deep ocean innovation. It is particularly important for funding pilot projects, high-risk research and development, and supporting enablers such as MRV systems. These foundational elements are consistently underfunded despite being critical for market building[34 83].

Beyond financing projects directly, concessional capital can play a broader enabling role. It can support infrastructure development, capacity building, and policy design such as funding technical assistance, building local expertise, and helping develop regulatory frameworks that promote sustainable industry growth. Concessional funds can also be structured to catalyze private capital by reducing project risk through blended finance models, making investments more attractive to commercial actors[83].

However, the effectiveness of concessional finance depends heavily on its design. Passive structures, such as "follower" funds that wait for commercial validation, tend to stall in frontier markets with few early movers. Philanthropic and sovereign innovation actors should be willing to fund deep-sea exploration and fundamental research at large scale as well as taking bold first-loss positions and anchor unconventional projects, particularly those that offer strategic or scientific value despite lacking short-term commercial signals[41].

Concessional funding must also prioritize feasibility and environmental integrity. Many deep ocean solutions still require rigorous impact assessments to prove their regenerative value and rule out unintended harm.

To support underexplored ecosystems and adapted innovation, fund structures should include flexible grant windows targeted at atypical proposals that may not meet traditional investment templates, accepting that game-changing discoveries need fundamental research and exploration and successful technologies rarely look conventional in their earliest form and require early, flexible backing to prove viability[34 41].

b. Lessons from blended finance and the climate innovation ecosystem

Lessons from blended finance and climate innovation show that success requires more than concessional capital, it demands ecosystem coordination, founder support, and clear commercial narratives. Programs like Breakthrough Energy Fellows and Project InnerSpace demonstrate how well-designed structures can close commercialization gaps and accelerate technology pipelines. Deep ocean sectors can draw from these models, while avoiding pitfalls seen in hybrid concessional structures that fail to effectively align capital streams.

Experience from the climate and energy sectors shows that concessional finance alone is not enough, it must be embedded within broader innovation ecosystems. Successful efforts combine concessional capital with institutional support systems, including founder fellowships, coalition building, and structured public-private interfaces to help close commercialization gaps.

Programs like Activate and Breakthrough Energy Fellows illustrate the value of entrepreneur-centered, non-dilutive funding for early-stage researchers embedded in technical institutions. These models are especially relevant for ocean sectors like biotechnology and MRV, where deep technical expertise is needed but commercialization pathways remain underdeveloped[73 74].

Similarly, Project InnerSpace (i.e., a geothermal advocacy initiative) has demonstrated how coordinated messaging, regulatory engagement, and ecosystem-level visibility can surface hidden risks, align funders, and build support across public and private actors. deep ocean innovation would benefit from analogous coalition models that raise awareness and create a shared vision for sector growth[75].

However, not all blended finance structures succeed. Hybrid models often struggle to coordinate commercial and concessional capital flows effectively[77]. A key insight from more successful vehicles is that they tend to share four core design traits[76]:

1. Alignment of objectives across public, private, and philanthropic actors
2. Use of guarantees, first-loss layers, and local expertise to reduce investor risk
3. Credible fund managers or institutional anchors that build trust with capital providers
4. Timely, simple, and flexible structures that minimize transaction friction

Finally, it is recommended to start with a commercial narrative and layering in concessional or grant support as a de-risking tool, rather than leading with public funding alone. This approach helps maintain discipline in project design while ensuring long-term sustainability[77].

c. Strategic role of PDBs, philanthropic capital, and sovereign innovation funds

Public development banks (PDBs), philanthropic organizations, and sovereign innovation funds are uniquely positioned to close early- and mid-stage financing gaps in emerging deep ocean sectors. Yet despite mandates that align with ocean innovation, few currently prioritize it. Estimates suggest that PDBs collectively contribute no more than US$4—5 billion annually to ocean-related sectors. With most actors operating at modest volumes, greater coordination across these institutions could unlock catalytic capital, support blended finance structures, and establish replicable governance models tailored to frontier marine innovation.

Public Development Banks (PDBs), philanthropic funders, and sovereign innovation funds are especially well-positioned to close early- and mid-stage financing gaps in frontier sectors like marine biotechnology, mCDR, and marine energy. These institutions are often the only actors willing to fund projects in the absence of private validation, first-loss protection, or supporting infrastructure.

As noted earlier, across seven assessed PDBs[22], an estimated $4—5 billion per year is committed or disbursed to the ocean economy. Among the largest contributors, the EIB provided €7.3 billion in ocean-related lending between 2019 and 2023. and AFD allocates €850 million per year. The Asian Development Bank (ADB) committed to expand its financing and technical assistance for ocean health and the marine economy to $5 billion between 2019 and 2024, including cofinancing from partners. Others have made smaller but notable contributions. KfW committed €227 million toward SDG 14 in 2023. The World Bank's PROBLUE program has scaled its technical portfolio to $182 million. USAID announced $103 million in ocean conservation funding, and Sida contributed $65 million in 2021.

Philanthropic capital continues to play a catalytic role, particularly through outcome-based models that reward measurable results rather than short-term financial returns. Institutions such as the Gates Foundation have successfully deployed this approach in global health and development, and similar mechanisms could be adapted to support ocean and climate innovation[33].

In the context of early-stage ocean technologies, such as biotechnology or biodiversity data systems, non-dilutive capital often depends on clear licensing and intellectual property terms. Public and philanthropic funding will increasingly require compliance with benefit-sharing frameworks and respect for data sovereignty, especially in biodiversity-rich countries[33].

Sovereign innovation funds are another promising mechanism. Australia's Clean Energy Finance Corporation (CEFC) has emerged as a leading example of a green bank model, using state-backed capital to support unproven technologies and crowd in commercial co-investment[78].

Although few of these institutions currently prioritize ocean-based innovation, their mandates and financial instruments offer institutional blueprints that could be adapted. This includes concessional project finance, guarantee mechanisms, and pooled R&D investments.

Greater coordination among these actors would help consolidate catalytic capital, standardize early-stage funding models, and establish shared governance tools for emerging ocean technologies. By working together, they could accelerate the transition from promising prototypes to investable, scalable solutions.

3.3 Suggestion of selected flagship financing instruments to bolster specific regenerative uses of the deep ocean (detailed concepts)

A National nature capital fund would enable countries to govern marine biodiversity as a strategic asset while capturing value from bioprospecting and digital sequence data. A deep tech cluster, requiring $400—500 million in blended capital, would co-locate labs, capital, and testing infrastructure to accelerate commercialization of ocean-based hardware and biotech. A dedicated FOAK project finance facility would bridge the “valley of death” for first-of-a-kind marine energy deployments, leveraging project finance-like loans and potentially tapping into the $65—70 trillion pool held by sovereign wealth and pension funds. Together, these instruments form a replicable architecture for de-risking innovation, attracting diverse capital, and positioning ocean nations at the frontier of the regenerative economy.

a. National nature capital funds

National nature capital funds would enable countries to assert sovereignty over marine natural capital, starting with genetic resources and data, while investing in the science, infrastructure, and governance needed to manage these assets strategically. DSI and IP licensing offer near-term monetization as a minimum viable product, but the fund’s broader purpose is to channel patient capital into biodiversity mapping, ecosystem stewardship, and long-term value creation. This model allows countries to retain control over their biodiversity wealth, shape equitable bioeconomy pathways, and serve as a sovereign anchor for future marine finance.

i. The concept

Business models in scope: Biotechnology, energy (geothermal and geological hydrogen), marine CDR.

A National Nature Capital Fund is a sovereign financing platform designed to recognize and generate value from marine ecosystem services. It combines an asset strategy, preserving marine natural capital, with a cashflow strategy that monetizes selected services, such as bioprospecting and biodiversity data licensing. These early pathways serve as a minimum viable product, demonstrating feasibility while laying the foundation for longer-term investments in science, data infrastructure, and conservation[33] [34] [35].

The fund would consolidate marine genetic and ecological data into a national ledger, convert it into licensable IP, and offer controlled access to domestic and international users. Inspired by biodiversity banking, sovereign innovation funds, and natural capital accounting frameworks, the model positions biodiversity not just as a public good but as a strategic asset. Over time, the fund would evolve into a broader platform supporting biodiversity mapping, MRV infrastructure, and ecosystem health, reinforcing national sovereignty and positioning countries in the emerging blue economy.

ii. Why a national nature capital fund?

A national nature capital fund offers three main advantages. First, it ensures equity and control, allowing biodiversity-rich nations to retain ownership of marine genetic resources and secure a share of downstream value. Second, it reflects strategic relevance: countries are increasingly treating biodiversity data as national assets, as seen in the U.S. National Security Council’s 2025 biotechnology strategy. Third, it brings the scale necessary to support infrastructure development by building the legal, scientific, and data systems needed to manage marine natural capital effectively.

Photo by Masayuki Agawa / Ocean Image Bank

iii. What would this fund look like structurally?

The Nature Capital Fund would operate as a multi-capital platform seeded by public investment and open to philanthropic, concessional, and private co-finance. It would manage a national biodiversity data ledger, retain IP rights, license access, and finance activities such as bioprospecting, sequencing, and biodiversity mapping. Revenues would be reinvested in science ecosystems, including labs, IP banks, and conservation infrastructure.

Indicative fund expenditures would cover not only biodiversity data generation (sampling, sequencing, analysis), but also enabling and stewardship costs such as Marine Protected Area (MPA) management, benefit-sharing programs, permitting and compliance, secure digital infrastructure, and core fund administration and operations (see **Annex 16.** for a breakdown of indicative cost elements)[33].

Countries could adopt different models: some may export raw datasets, while others refine them into higher-value IP. Success would depend on strong IP governance, clear ROI models, costed sequencing and compliance processes, and pilot programs to test monetization pathways. Involving public and private interests within the same structure will also require robust governance to balance commercial incentives with public-good objectives and ensure long-term trust in the fund's operations. Crucially, commercialization must support conservation and domestic capacity-building.

iv. How it would work

The fund would connect early-stage biodiversity discovery to market applications by underwriting data generation, securing IP rights, and structuring access partnerships. Governance safeguards would ensure equity and transparency, particularly for countries with limited scientific infrastructure. In ABNJ, sovereign or regional fund structures could help shape global governance norms around DSI, benefit-sharing, and access.

Implementation should start with clear jurisdictional areas like EEZs, align with national IP frameworks, and secure ownership early, before AI-driven platforms commodify raw data. Regional hubs could support MRV, arbitration, and shared governance. An international network of northern and southern local clusters could also be fostered to promote data sharing, joint sample collection, genomic analyses, and shared stewardship of ocean conservation rights[38].

Funding sources may include sovereign contributions, philanthropic grants, private sector co-investment, and public procurement schemes linked to biodiversity or blue carbon outcomes.

In parallel, emerging international mechanisms could complement national fund models. For example, broad-use "Conservation Units" or "Conservation Credits" could be developed under an international initiative, enabling their use for offsetting or compensation purposes. An International Ocean Conservation Fund could also be explored to negotiate such credits and channel financing toward ocean conservation initiatives[38].

Models such as Norway's sovereign wealth fund[79], Singapore's Temasek[80], and Costa Rica's genetic access frameworks show how strategic public finance can manage natural assets[81]. The Seychelles' blue bond and debt-for-nature swap demonstrate how marine conservation can be integrated into sovereign financial planning[82]. These precedents underscore the potential of nature-linked finance to align national development, sovereignty, and ecosystem regeneration.

b. Deep ocean deep tech cluster

A dedicated deep ocean deep tech cluster would consolidate innovation infrastructure, capital, and expertise to accelerate commercialization of frontier technologies. By integrating labs, accelerators, venture studios, and strategic offtakers in a single ecosystem, the cluster would address early-stage barriers and catalyze cross-sector innovation. Based on benchmarks (e.g., The Engine, AstraZeneca, Northvolt Labs), establishing such a world-class cluster would require $400—500 million in multi-year investment and unlock up to $15 billion in economic value over the next decade by enabling the commercialization of breakthrough IP, creation of venture-backed startups, development of supporting infrastructure and analytics services, and attraction of blended finance.

i. The concept

Business models in scope: Deep ocean exploration, life sciences, energy (geothermal and geological hydrogen), ecosystem services.

A deep ocean deep tech cluster is envisioned as a geographically anchored innovation cluster that brings together marine labs, venture studios, seed-stage investors, and academic institutions, co-located to accelerate commercialization of deep ocean technologies. The cluster would draw inspiration from global deep tech ecosystems where academic R&D, venture capital, and prototyping infrastructure are closely integrated[35 63].

Designed to support both hardware deep tech and life sciences pipelines, the cluster would connect academic institutions, corporate offtakers, and blue innovation accelerators to foster cross-sector alignment[83].

ii. Why a deep ocean deep tech cluster?

A co-located cluster offers strategic relevance by consolidating early-stage resources and capabilities, directly addressing structural barriers in deep ocean innovation. Many startups in this space require specialized lab environments, at-sea testing, and infrastructure that conventional incubators or venture capital models rarely provide. This infrastructure gap often becomes a critical bottleneck in development.

By pooling shared infrastructure (of which exploration and at sea testing), fundamental and applied sciences as well as technical talents, and blended finance mechanisms, the cluster would increase capital efficiency, de-risk early innovation, and enable philanthropic and public funding to generate greater catalytic impact. It would also facilitate smoother progression from fundamental research to ideation and early incubation to commercial scale-up by connecting startups with strategic buyers and later-stage investors.

Moreover, the cluster could accelerate regulatory processes and field validation by co-locating permitting hubs and deployment partners, which would shorten time-to-market for solutions requiring in-water trials[50].

iii. What would this fund look like structurally?

A world-class deep ocean Cluster would be structured across three core verticals, each representing a stage in the innovation pipeline, from science to commercialization. These verticals would be physically co-located to allow rapid iteration, while being supported by non-co-located partners such as offshore test vessels and global offtakers through structured collaboration mechanisms.

1. Fundamental science and biodiversity exploration

This vertical would be anchored by global research institutes and academic partners focused on deep ocean science and biodiversity mapping. It would be linked directly to applied innovation through co-located lab infrastructure and data integration systems.

2. Tech IP origination and incubation

Equipped with both wet and dry laboratories, this vertical would enable experimentation, sample analysis, and development of hardware tools such as sensors, MRV/impact assessment systems, and biomaterials. It would include incubation programs offering access to data, infrastructure, and mentorship for early-stage companies in biotech, energy, and carbon removal. Venture or startup studios would play a bridging role (of science-to-market), scouting IP from research labs, validating early traction, assembling founding teams, and providing operational support[84].

3. Investment and offtake

Risk-tolerant capital from early-stage venture funds would support frontier innovation, while late-stage VC, private equity, or corporate offtakers would anchor downstream scale-up and market access beyond the pilot phase

4. Other partnership linkages (not co-located but essential)

Though not physically embedded, critical partners such as in-situ testing infrastructure, global academic collaborators, and corporate buyers would provide essential connectivity and de-risk market access. Global corporate offtakers could function similarly to advance market commitments by validating products and helping unlock later-stage finance[34].

Potential locations could include regions with ocean access, international connectivity, and alignment with blue economy or ABNJ priorities. For example:

- → California (e.g., MBARI), Norway, the UK, and the Netherlands, combining offshore industries with innovation ecosystems.
  France's overseas territories, offering biodiversity proximity and alignment with Global South leadership[99].
- → The Arabian Peninsula, with growing student interest, industrial capacity, and relatively low visa barriers.
- → Scandinavia, where biotech interest (e.g., from firms like Novo Nordisk) could anchor health and bio-based verticals[99].

Establishing such a cluster is estimated to require $400—500 million in upfront and multi-year investment, based on global benchmarks such as The Engine Ventures[6], AstraZeneca[7], and Northvolt Labs[8]. Although the cluster itself may not directly yield financial returns, it could unlock up to $15 billion in economic value over the next decade by enabling the commercialization of breakthrough IP, creation of venture-backed startups, development of supporting infrastructure and analytics services, and attraction of blended finance[66]. In addition, the cluster would generate broader benefits such as regional innovation spillovers, ecosystem strengthening, and job creation.

See **Annex 17.** for lessons from grand-scale science ventures leveraging patient capital.

iv. How it would work

To be effective, the cluster must integrate several design elements:

- → Pilot locations and financing instruments for in-water trials, as well as partnerships with classification societies (e.g., DNV, Lloyd's, Bureau Veritas) to ensure commercial acceptability of emerging technologies.
- → A vertical structure should link incubation with Series A/B support and downstream offtake arrangements[99].
- → Quantitative performance metrics, such as daily survey targets, can help sharpen research focus and make innovation pipelines more investable[45].
- → Flexibility will be crucial. Because many startups in this space require non-standard infrastructure, small grant schemes enabling individuals to "hack together" testing spaces may be more effective than fixed capital investments in buildings[41].
- → Clusters should also be modular, allowing teams to operate autonomously to reduce bureaucracy and retain agility[34].
- → In-situ testing capabilities would be essential, potentially secured through partnerships with marine protected areas, national ocean testbeds, oil rigs, or desalination plants.

International academic partnerships and open innovation protocols would ensure scientific credibility and global relevance. Non-domestic collaborators could help validate discoveries and open commercialization channels beyond the host country.

The cluster would be anchored by catalytic capital (grants, concessional loans, and risk-tolerant equity) to de-risk R&D and pilot deployment. Mission-aligned foundations and public funders could cover ecosystem functions, while strategic corporate partners could commit to early purchasing or scaling solutions. It could also host neutral deep ocean survey efforts, supported by institutions like Pew's Seabed 2030 and API Oceans.

c. Project finance for 'First-of-A-Kind' commercial pilots

First-of-a-Kind (FOAK) commercial projects in deep ocean sectors, such as geothermal and geological hydrogen, face steep barriers in transitioning from pilot to scale. These ventures often require hundreds of millions in capital before proving market viability, making them too risky for traditional lenders and too mature for venture capital. This subchapter proposes a dedicated FOAK project finance instrument to bridge this "valley of death," deploying milestone-based capital to support early deployments, while leveraging and helping catalyze upstream exploration and foundational science critical to project developments.

i. The concept

Business-model in scopes: Energy (geothermal and geological hydrogen) and other capital-intensive ocean innovations.

First-of-a-Kind (FOAK) commercial pilots refer to large-scale infrastructure projects that mark the first real-world deployment of a novel or under-tested technology, projects with high capital intensity, significant completion and performance risk, and limited historical data. In the ocean sector, this includes technologies such as offshore geothermal plants or geological hydrogen wells.

Traditional project finance (used in roads, power plants, or ports) depends on predictable cash flows, low technology risk, and long-term contracts. FOAK projects, by contrast, face high uncertainty in technical performance, permitting, market uptake, and revenue. As a result, they often fall into a capital gap: too expensive for grants or VC, and too risky for commercial lenders[64].

This model proposes a dedicated marine FOAK finance facility, using a project finance-style debt structure, with milestone-based disbursements and deferred repayment until commercial viability is demonstrated. Rather than relying on blanket guarantees or equity dilution, the fund would reflect the realities of FOAK risk.

The proposed FOAK facility would offer structured loans disbursed in tranches, each aligned to technical or operational milestones, such as geothermal gradient confirmation, hydrogen yield, or permitting approval. Repayments would begin only after commercial viability is demonstrated. The emphasis is not on providing blanket guarantees, but on building financing frameworks that reflect the uncertainty and learning curves inherent in early deployments.

Critically, this approach fills a well-known gap in the energy innovation landscape. Even proven solutions have faced funding barriers at their first infrastructure scale-up stage. The Northvolt case, despite its bankruptcy, illustrates how custom financing structures, public-private support, and anchor customers can make FOAK ventures bankable, despite their risk profile (see **Annex 18.** for Northvolt case study).

While the FOAK facility is focused on late-stage commercial deployments, these projects will depend on and help catalyze upstream exploration, baseline resource characterization, and foundational science, which are critical to de-risking project development and informing milestone design.

ii. Why a project finance for 'First-of-A-Kind' commercial pilots?

FOAK projects are typically caught between two funding voids: they are too expensive and too unproven for commercial banks. This is particularly true in the ocean energy space, where projects may exceed $500 million in capital requirements and face long development cycles.

A tailored FOAK project finance enables large-scale debt to flow into innovation, while tying risk exposure to specific milestones such as resource confirmation, permitting, or pilot deployment. This model allows institutional investors, especially sovereign wealth funds (SWFs) and pension funds, to participate without bearing early-stage risk.


Photo by OceanX

Concessional or long-term capital is required to absorb early-stage risk and extend repayment timelines. SWFs and pension funds are ideally positioned to fill this gap. With a combined $65–70 trillion in assets under management globally[9 10], even allocating just 0.1% to FOAK infrastructure could unlock over $60 billion in new capital, enough to scale significant pilots across ocean energy, biotech, and carbon removal. For these institutions, the downside is negligible; for FOAK markets, the upside is transformative.

iii. What would this fund look like structurally?

The FOAK facility would issue project-specific, milestone-tied loans with flexible repayment schedules. Disbursement would be linked to technical and regulatory milestones (e.g., geothermal gradient confirmation, hydrogen yield, grid interconnection). Grace periods would reflect the long timelines typical of ocean infrastructure.

The fund would specifically target hardware-heavy, capital-intensive ventures in marine energy and adjacent sectors. It would not replace grants or VC, but act as a bridging mechanism, unlocking project finance for unproven but promising infrastructure.

iv. How it would work

Repayment obligations would be tied to the project's cash flow maturity, with flexible terms that reflect learning curves and long development cycles. The goal is not to guarantee success, but to provide a structured path to first deployment, a step that unlocks private investment, builds investor confidence, and generates real-world data.

The facility would collaborate with exploration vessels and institutions, fundamental research institutes, classification societies, permitting authorities, and offtake partners to validate performance. Catalytic public or philanthropic capital could serve as first-loss buffers or guarantee layers, further crowding in institutional finance.

Roadmap and call to action

The deep ocean offers a pathway to economic prosperity that enhances, rather than exploits, the planet's natural capital. This report outlines an investable alternative that aligns economic opportunity with biodiversity stewardship, climate resilience, and global equity. Foundational building blocks are now emerging, including the three flagship financial instruments proposed in this report, from National Nature Capital Funds to capture value from marine natural capital and data, to a Deep Ocean Deep Tech Cluster to accelerate commercialization of ocean-based technologies, and FOAK project finance facilities to bridge the capital gap for first-of-a-kind and capital-intensive projects.

The next phase can begin by turning this vision into operational Deep Ocean Funds and concrete investment pathways. Three priority actions emerge:

- → Refine and prototype the flagship financing instruments proposed in this report, in partnership with leading public and private actors.
- → Initiate structured engagement with priority countries, those with large EEZs, rich biodiversity, strong research capacity, and robust governance, to co-develop national-level fund strategies.
- → Mobilize national champions and institutional anchors, ministries of science and environment, sovereign wealth funds, and leading universities, to embed these funds in domestic priorities and long-term stewardship models.

This is a call to action:

Building a resilient and inclusive deep ocean economy will require deliberate choices and coordinated leadership. The time to act is now, through focused collaboration across science, finance, governance, and national leadership, to turn this roadmap into reality.

Photo by OceanX

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Annexes

Annex 1. Illustrative examples of marine biotechnology products and use cases across industries[15]

Sector	Example applications
Pharmaceuticals	Antibiotics, anticancer compounds, antiviral agents, drug discovery pipelines
Nutraceuticals & Functional Foods	Omega-3 fatty acids, peptides, enzymes, vitamins, food supplements
Cosmetics	Anti-aging products, bioactive compounds from seaweed and algae
Biomaterials & Bio-inspired Materials	Bone scaffolds, bio-adhesives, drug delivery systems, bio-composites
Enzymes	Industrial enzymes (e.g., from extremophiles), food processing, plastic degradation
Bioenergy	Biofuels from algae and seaweed, molecular hydrogen from photosynthetic algae
Bioremediation	Oil degradation, heavy metal removal, microplastic degradation using algae and bacteria
Diagnostics	Molecular markers (e.g., GFP), biosensors
Chemicals & Industrial Products	Biopolymers, biosurfactants, biolubricants, biosolvents

Annex 2. Mapping of key marine biodiversity sources and their potential applications[15]

Source	Example applications
Microorganisms	Novel enzymes, antibiotics, biosurfactants, plastics degradation, biofuels
Microalgae	Nutraceuticals, cosmetics, biofuels, pigments, wastewater treatment
Macroalgae (Seaweed)	Food ingredients, nutraceuticals, biofuels, bioplastics, wastewater biosorbents
Marine Fungi	Pharmacological metabolites, biosurfactants, enzymes, bioremediation
Bacteria & Archaea	Therapeutics, extremophile enzymes for harsh industrial processes
Extremophiles	Industrial enzymes, thermostable compounds, unique biocatalysts
Invertebrates (e.g., sponges, corals)	Antifouling, biomaterials, pharmacological compounds
Diatoms	Nanomaterials, fillers for polymers, biomedical devices
Fish & Shellfish	Aquaculture breeding, cell-based seafood, fish waste valorization
Sponge Symbionts	Untapped chemical diversity, bioactive metabolites
Waste & By-products	Fertilizers, packaging materials, bioremediation, bioplastics

Annex 3. Mapping of offshore geothermal's co-benefits and responsible development pathways

Co-benefit / pathway	Description
Multi-product generation	Generating multiple co-products beyond electricity, including fresh water, green hydrogen, and green ammonia, offering cascading benefits and diversified value chains.
Support to ecosystem services	Contributing to local ecosystem services, including controlled ocean fertilization and fisheries enhancement, though these require further scientific validation.
Inclusive local economic opportunities	Creating significant opportunities for local capacity building, marine science employment, and inclusive economic participation, particularly for developing and coastal nations.
Circular economy alignment	Aligning naturally with circular economy principles, enabling modular construction, repurposing of oil and gas infrastructure, and minimizing environmental footprint.
Environmental safeguards and governance alignment	Requiring robust environmental protocols, including vent and brine pool exclusion zones, baseline studies, and adaptation of ISA licensing frameworks, incorporating best practices from offshore petroleum and onshore geothermal sectors.

Annex 4. Descriptions of different mCDR approaches, associated methods, and co-benefits

mCDR approach	Definition and method	Additional notes/ co-benefits	Deep-sea impact considerations[52] [53]
Ocean Alkalinity Enhancement (OAE)	Adds alkaline materials (e.g., basalt, limestone) to seawater, converting CO_2 into stable bicarbonates stored for ~10,000 years	May reduce ocean acidification, especially in vulnerable coral reef ecosystems.	Mineral addition may cause clogging of respiratory and filtration structures of deep-sea organisms by small particles, leaching of trace metals, and secondary food-web impacts of shading.
Vertical Flow Manipulation (Upwelling/ Downwelling)	Aims to stimulate biological carbon drawdown or enhance deep ocean sequestration through artificial circulation.	Permanence and ecological risks remain highly uncertain; current deployment negligible.	Potential entrainment of deep water and mortality of vertical migrators and planktonic larvae; carbonate fluxes may affect deep-sea chemistry.
Enhanced Fertilization	Introduces nutrients (e.g., iron, nitrogen) into ocean zones to stimulate phytoplankton blooms; harvested algae can be sunk to >1,000m for storage.	Theoretical sequestration >1 $GtCO_2$/year; system design and species are key variables.	Increased particulate organic carbon flux can lead to oxygen loss and acidification. Smaller particles mean slower flux, so more impacts to deep pelagic (i.e. water column) organisms than with organic matter sinking. Out-of-season sinking of organic matter can disrupt reproductive cycles and lead to changes in life-history phenology.
Deep-sea Biomass or CO_2 Storage	Involves injecting captured CO_2 into geological formations below the seabed or sinking seaweed/biomass into anoxic deep waters.	Very low per-area sequestration density (~1.3 tCO_2/year per km^2 seaweed farmed and sunk).	**Organic matter sinking:** Amount, timing, location, underlying oxygen conditions, and source of organic material are important considerations. Risks include smothering and seafloor habitat modification from added organic matter, increased bacterial respiration causing local oxygen loss and acidification, and pesticide exposure from agricultural material. **Carbon capture and storage:** Installation of CO_2 injection infrastructure may disrupt seafloor habitats, resulting in habitat loss and fragmentation, and impact ecosystem functions such as nutrient cycling and carbon sequestration. CO_2 leakage from storage reservoirs and subsequent organismal exposure to low pH conditions is also a concern.

Annex 5. Key international instruments for deep ocean governance and benefit-sharing

1. BBNJ Agreement — Implementation Pillars

The Agreement on Biodiversity Beyond National Jurisdiction (BBNJ), adopted in June 2023, establishes the first comprehensive legal framework for the conservation and sustainable use of marine biodiversity in Areas Beyond National Jurisdiction (ABNJ). Its implementation is structured around four core pillars:

- Marine Protected Areas (MPAs): Mechanisms for designating and managing MPAs in ABNJ to protect biodiversity hotspots and vulnerable ecosystems.
- Environmental Impact Assessments (EIAs): Enhanced requirements for pre-activity impact assessment in ABNJ, with scientific review and transparency obligations.
- Capacity-Building and Marine Technology Transfer: Tailored support for developing countries to access scientific tools, training, and deep-sea technologies.
- Access and Benefit-Sharing (ABS) for Marine Genetic Resources (MGRs): A global framework to track the collection, use, and sharing of MGRs and associated Digital Sequence Information (DSI).

A Clearing-House Mechanism (CHM) will be developed to register activities, ensure data transparency, and facilitate benefit-sharing.

2. Evolving ABS Instruments Under BBNJ

In addition to its legal framework, the BBNJ Agreement introduces several instruments designed to improve equity and enforceability:

- Open-access scientific databases for MGRs and DSI.
- Standardized Material Transfer Agreements (MTAs) to govern physical and digital samples.
- Non-monetary benefit-sharing provisions, such as:
  - → Joint research
  - → Data sharing
  - → Technical training
  - → Participation in scientific expeditions
- A placeholder for future monetary mechanisms, enabling scalable and enforceable funding streams.

3. The CBD's Cali Fund (emerging model)

The Convention on Biological Diversity (CBD) has proposed the "Cali Fund" as a potential monetary benefit-sharing model for the digital age. Key elements include:

- Contributions:
  - → 1% of profits or
  - → 0.1% of revenues from large-scale DSI users (e.g., biotech, pharmaceutical, or genomics companies).
- Distribution:
  - → At least 50% of proceeds directed to Indigenous Peoples and Local Communities (IPLCs).
- The model is designed to scale alongside growing commercial reliance on digital genetic resources.

4. The Nagoya Protocol and CBD Article 15

The Nagoya Protocol (2010), as a supplement to the CBD, operationalizes benefit-sharing through:

- Legal certainty and transparency in how genetic resources are accessed and used.
- Obligations for researchers and companies to obtain:
  - → Prior Informed Consent (PIC) from national authorities or local rights holders.
  - → Mutually Agreed Terms (MAT) for how benefits (monetary or non-monetary) will be shared.

The Nagoya Protocol addresses the historical issue of biopiracy and aims to create fair and enforceable channels for local communities and nations to benefit from the use of their biodiversity.

Negotiations are ongoing to update the Protocol to explicitly address Digital Sequence Information (DSI), which is currently outside its formal scope.

Annex 6. Overview of biodiscovery pipelines and methodologies in marine biotechnology[15]

Stage	Methodologies & tools	Notes
Sample Collection	Field sampling, remote-operated vehicles (ROVs), autonomous underwater vehicles (AUVs)	High cost and logistical complexity in deep-sea sampling
Genomics & Metagenomics	High-Throughput Sequencing (HTS), genome mining, metagenomics	Allows analysis of whole microbial communities without culturing
Metabolomics	Mass spectrometry, NMR, systems biology-assisted profiling	For identifying bioactive metabolites and metabolic pathways
Bioactivity Screening & Bioassays	In vitro, cell-based, in vivo bioassays combined with metabolomics	Detects functional properties such as anticancer or anti-inflammatory activity
Natural Product Chemistry	Isolation and structural elucidation using chromatography, spectroscopy	Identifies novel bioactive compounds
Genetic & Metabolic Engineering	Pathway engineering, strain optimization, synthetic biology	Improves yield, scalability, and commercial viability
Bioprocessing & Scale-Up	Fermentation, bioreactors, real-time process monitoring	Key barrier for commercialization due to strain instability and growth requirements
Data Management & Access	Biobanks, data platforms, MRV systems, ABS compliance	Supports traceability, access management, and benefit-sharing

Annex 7. Examples of company-led pipeline activities and innovations in marine biotechnology

Company	Approach / highlight
PharmaMar	Continues to discover bioactive compounds from marine organisms, including the FDA-approved cancer drug Trabectedin, derived from a sea squirt (pharmaceuticals).
Illumina	Applies sequence-driven discovery to identify genetic traits such as nutrient uptake and heat resistance, with applications across agriculture and health sectors.
Givaudan	Explores marine algae and seaweed to develop novel ingredients for skincare and fragrances (personal care).
DSM-Firmenich	Conducts microbial bioprospecting in algae and fungi to produce vitamins, omega-3 fatty acids, and biopharmaceuticals (nutrition, biopharma).
Novozymes	Leverages marine microbes for applications in biofuels, agriculture, detergents, and food processing (industrial biotech).
AstraZeneca	Partners with academic institutions to explore marine organisms as potential sources for pharmaceutical compounds.
Basecamp Research	Pioneers a non-extractive, data-driven model of bioprospecting, digitizing gene sequences rather than harvesting organisms; maintains a proprietary database of over 10 billion proteins; collaborates with Scripps, Bigelow Labs, and piloting ABS partnerships in Costa Rica (biodiversity data, synthetic biology, ABS).

Annex 8. Focused case study: Basecamp Research and Costa Rica ABS partnership[33]

Basecamp Research, founded in 2020, is pioneering a non-extractive, data-driven model of biological discovery, combining biodiversity informatics and synthetic biology to digitize gene sequences rather than harvesting organisms. AI models built on this dataset are used to generate synthetic biology solutions from natural sequences, offering pathways to industrial biotech innovation without the need for physical extraction.

Basecamp aligns with Access and Benefit-Sharing (ABS) protocols even in areas of international jurisdiction (e.g., international waters & Antarctica), despite there currently being no legal requirement, the formal adoption of the High Seas Treaty in 2023 highlights the importance of Basecamp anticipating the tightening of legal frameworks & the futureproofing of their work. Basecamp guarantees traceability as a principle of data stewardship and being able to accurately link value creation and value distribution. Without traceability you lose the link, and this counteracts the fundamental recognition of biodiversity as sovereign assets as in the 1992 CBD.

The company has established collaborations with leading marine science institutions, built on mutually beneficial partnerships where the portable DNA laboratory & training on this equipment forms an integral part of the value transfer as part of the agreed knowledge & value share. In Costa Rica, Basecamp is piloting an ABS and mutual knowledge & capacity sharing partnership designed to align biodiversity access with national innovation goals. The long-term ambition is to support Costa Rica's strategy to develop a domestic biosimilar and biotech industry. While conversations with local biotech firms are ongoing, the partnership currently focuses on capacity building and institutional partnerships, with no commercial applications or joint ventures yet established.

Annex 9. Cumulative TAM projections by sector (2026-2065)

1. Deep-sea mining

- **Total theoretical value of reserves:** \$8–16 trillion over 40 years[85]
- **Sustainable extraction scenario:** Adjusted to reflect a 20% exploitation cap (to preserve biodiversity and reference zones), the estimated cumulative market value is \$1.6–3.2 trillion
- **Time horizon:** 40 years, based on resource depletion timelines and parity with other TAM projections in this report

2. Marine biotechnology

- **Base market size in 2026:** \$8.74 billion[15]
- **Assumed CAGR:** ~10% annually[15], sustained over time
- **Cumulative market size over 40 years:** ~\$440 billion
  → This reflects compounded annual growth applied to the 2026 baseline over four decades.

3. Offshore geothermal energy

Scenario: Assumes offshore geothermal reaches 10% of IEA's global 800 GW geothermal capacity projection by 2050[46]

- **Installed capacity by 2050:** 8 GW
- **Annual energy output:** ~630 TWh/year (based on 90% capacity factor)
- **Electricity price in:** \$40/MWh[87]
- **Annual TAM in 2050:** 63,000,000 MWh/ year x \$40/MWh = ~\$25 billion/year

Ramp-up period (2026–2050):

- Linear growth from \$0 to \$25billion/year
- Average annual revenue: ~\$12 billion/year
- Total (25 years): **\$315 billion**

Plateau period (2050–2065):

- \$25 billion/year × 15 years = **\$380 billion**

Total cumulative market size (cumulative 40 years): ~\$700 billion

4. Marine CDR

Growth scenario:

- Market grows from \$0 in 2026 to \$500B/year by 2050[88]
- **Ramp-up period (2026-2050):** Annualized average of ~\$250B/year × 25 years = \$6.25 trillion
- **Plateau period (2050-2065):** \$500B/year × 15 years = **\$7.5 trillion**

Total projected market size (cumulative 40 years): \$13.75 trillion

Annex 10. Focused case study: Southern Iceland — a proof point for offshore geothermal development

Southern Iceland showcases how oceanic spreading centers can deliver world-class geothermal energy. Volcanic deposits over the North Atlantic Ridge have enabled onshore development of a system geologically tied to the seabed, offering a critical proof point for similar offshore projects globally.

Beyond power generation, such offshore geothermal systems can also produce green hydrogen or ammonia by electrolyzing turbine steam condensate directly at sea, allowing clean fuel export without the need for subsea power cables.

Annex 11. Information on examples of offshore geothermal pilots and feasibility studies

Country	Project / approach	Status / notes
Indonesia	Exploration of nearshore offshore geothermal potential in Java and Sumatra coasts where volcanic heat flows extend underwater.	Early-stage exploration; no operational offshore plants yet.
Norway	North Sea studies led by Equinor, SINTEF. Exploring repurposing oil and gas platforms for geothermal extraction from deep sedimentary basins.	Conceptual and feasibility stages; focused on platform reuse and subsea heat exchange systems.
New Zealand	Academic-led mapping of submarine geothermal systems near tectonic plate boundaries in Taupo Volcanic Zone and nearby offshore basins.	Research stage; potential for future energy development.

Annex 12. Detailed overview: solid-state thermoelectric units

What are solid-state thermoelectric units?

- Solid-state thermoelectrics convert heat directly into electricity using the Seebeck effect.
- These systems operate without any moving parts, fluids, or combustion, relying solely on solid-state materials, typically semiconductors.
- Key materials include bismuth telluride (Bi_2Te_3), skutterudites, and newer options like tin selenide (SnSe).

How do they work?

- A temperature difference across the thermoelectric material causes charge carriers (electrons or holes) to move.
- This movement generates a voltage and, when connected to a circuit, produces electric current.
- Thermoelectric modules consist of multiple such elements placed between a heat source and a heat sink.

Use cases in geothermal energy

- Low-temperature geothermal fields: Operate efficiently in the 100–300°C range, ideal where temperatures are too low for turbines (>150°C).
- Remote geothermal wells: Power sensors, pumps, or communication equipment at isolated boreholes.
- Waste heat recovery: Improve efficiency of traditional geothermal systems by capturing residual heat after turbine operation.

Advantages

- No moving parts → quiet, low maintenance, and long lifespan.
- Modular and scalable → from milliwatts to kilowatts, depending on system design.
- Compact footprint → ideal for constrained or mobile environments.
- Suitable for off-grid and autonomous systems in remote or inaccessible settings.

Limitations

- Low conversion efficiency: Typically 5—8%, compared to 30—40% for turbines.
- Material costs: High-performance thermoelectric materials remain expensive or scarce.
- Thermal management: Requires effective design to maintain a strong temperature gradient across the device.

Strategic relevance for deep ocean applications

- Enables electricity generation from deep-sea heat sources (e.g., hydrothermal vents) without drilling or large infrastructure.
- Can power autonomous robots, underwater observatories, or marine monitoring platforms for MPAs enforcement deep-sea mining oversight.
- Offers a low-impact, modular energy solution for remote seafloor deployment

Annex 13. Case study: West Iberia margin and Lost City hydrothermal fields

Two marine geological sites illustrate the untapped potential of natural hydrogen generation. At the Lost City hydrothermal field on the Mid-Atlantic Ridge, hydrogen production is estimated to be 10 to 100 times higher than that of typical volcanic hydrothermal vents, due to serpentinization of ultramafic rocks[89].

Meanwhile, the West Iberia passive margin, where mantle rocks are exposed beneath sedimentary cover, shows similarly promising signs. Drilling samples from serpentinites in this region yielded 120—300 mmol of hydrogen per kilogram of rock in early reaction stages, equivalent to roughly 2.4—6.7 liters of hydrogen gas per kilogram, under standard conditions. While modest per unit, the yield suggests that vast ultramafic formations in passive margins could potentially enable sustained subsurface hydrogen generation, pending further geological mapping and technological breakthroughs.

Annex 14. Update: Saudi Arabia's carbon market readiness

Saudi Arabia is demonstrating strong commitment to developing a comprehensive carbon market framework, providing opportunities for investment in carbon offset projects, including those related to marine and deep-sea carbon removal.

This ambition aligns with its Vision 2030 and net-zero targets, supported by several key developments:

- Launch of the Regional Voluntary Carbon Market Company (RVCMC): In November 2024, Saudi Arabia inaugurated its first carbon trading exchange during COP29, managed by RVCMC. This platform aims to position the Kingdom as a leading hub for voluntary carbon markets in the Middle East and North Africa (MENA) region[90].
- Accreditation of Validation and Verification Bodies (VVBs): As of May 2025, the Kingdom has accredited four VVBs to operate within its regulated carbon market, signalling progress in establishing a robust carbon crediting mechanism[91].
- Implementation of the Greenhouse Gas Crediting and Offsetting Mechanism (GCOM): Announced in 2022, GCOM is the first government-led carbon crediting mechanism in the Gulf region, designed to stimulate domestic and international climate action[92].
- Significant Market Growth Projections: The voluntary carbon credit market in Saudi Arabia is projected to grow at a compound annual growth rate (CAGR) of 28.4% from 2024 to 2030, reaching an estimated revenue of USD 124.6 million by 2030[93].

Annex 15. Mapping of funding and institutional activity in geological hydrogen

Category	Instituition / program	Region / country	Description / funding activity
Public Funding	U.S. DOE — Hydrogen Earthshot	United States	$9.5B committed for hydrogen hubs and subsurface science research
	Horizon Europe, Innovation Fund, IPCEI Hydrogen	European Union	~$4.5B annually across clean hydrogen projects, including geological hydrogen
	Government of France	France	Issued first exploration license for geological hydrogen (2023)
	NEDO, Moonshot Programs	Japan	Fund foundational hydrogen research, including marine geology
	Low-Carbon R&D Fund	Singapore	$55M for hydrogen innovation and related technologies
	Hydrogen Development Project	Sarawak, Malaysia	$4.2B investment in hydrogen production and infrastructure
	Licensing Regime for Hydrogen	South Australia	First dedicated legal framework for geological hydrogen development
Private Investment	Koloma	United States	Raised $90M for geological hydrogen exploration
	Gold Hydrogen	Australia	$20M secured via IPO
	Mantle8	France	€3.4M raised from Breakthrough Energy Ventures
	BP, Rio Tinto	Global	Exploring geological hydrogen as part of transition portfolios
	Temasek, GIC	Singapore	Investing in clean energy startups; potential future role in geological hydrogen
Philanthropic / Academic / MDBs	Mission Innovation — Hydrogen Mission	Global	Seed grants and technical assistance for early-stage hydrogen projects
	Grantham Foundation, Hydrogen Science Coalition, NSF, ERC	Global / US / EU	Funding for R&D and environmental assessments related to geological hydrogen
	ADB, World Bank	Asia / Global	Not yet active; potential future role if aligned with climate or development finance goals

Annex 16. Indicative cost elements for national nature capital funds

Ongoing (or initiating) MPA (Marine Protected Area) management

- Monitoring & Evaluation: Biodiversity assessments, remote sensing, community-based reporting.
- Education & Outreach: Community engagement and education programs.

Sampling and bioprospecting

- Field expeditions, sampling, DNA extraction, sequencing, analysis, metadata management.
- Permitting & Legal Compliance: Costs depend on national ABS frameworks.

Benefit-sharing and community investment mechanisms

- Community development, capacity-sharing / knowledge-sharing programs, cost per sample access, etc.

Digital infrastructure

- Systems for tracking genetic data, royalties, and benefit-sharing. May include cloud infrastructure for genomic data storage and analytics.

Fund administration and operations

- Core management functions, including personnel time, fund governance, legal and financial administration, and monitoring and reporting of fund performance.

Annex 17. Lessons from grand-scale science ventures: ISS and ITER

Like the International Space Station (ISS) and the International Thermonuclear Experimental Reactor (ITER), a deep ocean innovation cluster would require patient capital deployed over multi-decade horizons, not for short-term returns, but to generate long-term strategic, scientific, and economic value. ITER's total construction and operational costs are projected at $20—25 billion[94], with some estimates reaching $65 billion[95], reflecting the complexity and ambition of its fusion energy mission.

The ISS, meanwhile, has cost approximately $100 billion over its first decade[96] and requires around $4.1 billion annually to sustain operations in low Earth orbit[97]. Though demanding in terms of time and coordination, both ventures have delivered far-reaching spillover effects, from breakthroughs in robotics and materials science to international governance frameworks and public—private collaboration models. A deep ocean tech cluster, backed by similarly patient and coordinated investment, could deliver comparable cross-sector impact, strengthening marine robotics, environmental monitoring, bioengineering, and data systems, while anchoring the infrastructure for a regenerative ocean economy.

Annex 18. Northvolt — Financing the first gigafactory[98]

Northvolt, a Swedish battery manufacturer, exemplifies the challenges FOAK projects face, even when the core technology is commercially proven. Building Europe's first large-scale gigafactory required over $1.6 billion in upfront capital. Traditional lenders were hesitant, given the project's novelty, capital intensity, and lack of early revenue.

To bridge this gap, Northvolt assembled a blended capital stack. BNP Paribas led a $1.6 billion syndicated loan, backed by government guarantees and institutional investors. The project also leveraged pooled infrastructure and early anchor customers to demonstrate offtake readiness.

While Northvolt ultimately faced bankruptcy, its early financing structure remains a useful illustration of how FOAK tools, when deployed with strategic alignment and public-private support, can unlock high-impact industrial projects that would otherwise struggle to reach commercial scale.

Annex 19. Other emerging business models in deep ocean industries

Business model	Description and highlights
Deep-sea Water Production and Desalination[99, 100]	Deep-seawater desalination offers lower treatment costs, cleaner water output, and higher energy efficiency by leveraging pressure gradients. Companies like OceanWell are commercializing deep-sea water wells, reducing brine discharge and energy use, supported by a $11 million Series A round (2024). FLOCEAN explores offshore renewable energy-integrated desalination, blending wave/tidal energy with water systems for island and coastal communities.
Ocean-based Energy Storage and Generation[34]	Concepts such as salinity gradient systems and temperature differentials near island nations offer potential for energy generation and desalination, though these remain at early conceptual stages with limited demonstration.
Ocean Direct Air Capture (DAC)	Early-stage concepts applying DAC technologies in offshore environments to capture atmospheric CO_2 directly over ocean spaces; currently at a conceptual level with no known commercial pilots.
Wave Power (e.g., Calwave)[50]	Technologies for harnessing wave energy, such as Calwave, which faced permitting challenges in California, highlighting ongoing regulatory hurdles to commercialization.
Deepwater Irrigation for Algae Growth[50]	Emerging concept using deepwater flows to stimulate algae growth for biomass or CDR applications; still exploratory with no commercial-scale demonstrations.
Ecosystem Service Markets (e.g., Deacidification Credits)[50]	Market mechanisms such as Australia's Great Barrier Reef Credit Scheme aim to monetize ecosystem services like ocean deacidification.

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