OCEAN ENTERPRISE INITIATIVE

Dialogues with Industry
Background Paper

Ocean Observing of the Future: Sensors, Instruments, Platforms and the Market Ahead

**Cover photo: Oceaneering ROV Global Explorer rests on deck, under an extremely clear night sky above, over Hudson Canyon in the Atlantic Ocean.*

Table of Contents

Background

The Ocean Enterprise Initiative is a global effort that spearheads innovation, thought leadership, and economic development within the Ocean Enterprise. It is led by the Marine Technology Society (MTS), Global Ocean Observing System (GOOS), National Oceanic and Atmospheric Administration (NOAA), and Industry (Kongsberg Discovery and L3Harris).
The first successful series of the *Dialogues with Industry* (hereafter *Dialogues)* took place in September 2022-January 2023 and explored how to mature the Ocean Enterprise to deliver essential societal, economic, and environmental benefits. This effort culminated in the *Dialogues with Industry* Roadmap (hereafter Roadmap). The Ocean Enterprise Initiative is the structure to implement recommendations from the Roadmap guided by three goals:

- Improving the Marketplace,
- Collaboration to Grow and Impact Change,
- Shaping the Future

The *Dialogues* are a signature pillar of the Ocean Enterprise Initiative. The second *Dialogues* took place from January – February 2025 and focused on Harmful Algal Blooms. Access the summary report here.

The third *Dialogues* took place in October – November 2025 and was focused on the future of ocean observing. The background paper set the context for the discussion.
The success of the *Dialogues* stems from bringing together all components of the Ocean Enterprise through facilitated discussions across the entire Ocean Information Value Chain, as depicted in **Figure 1**. The *Dialogues* serve as a foundational framework for understanding the obstacles towards an ocean observing market via the Ocean Information Value Chain. They aim to identify the demand, relevant stakeholders, challenges, and opportunities necessary to unlock economic potential while meeting the increasing need for actionable ocean information.

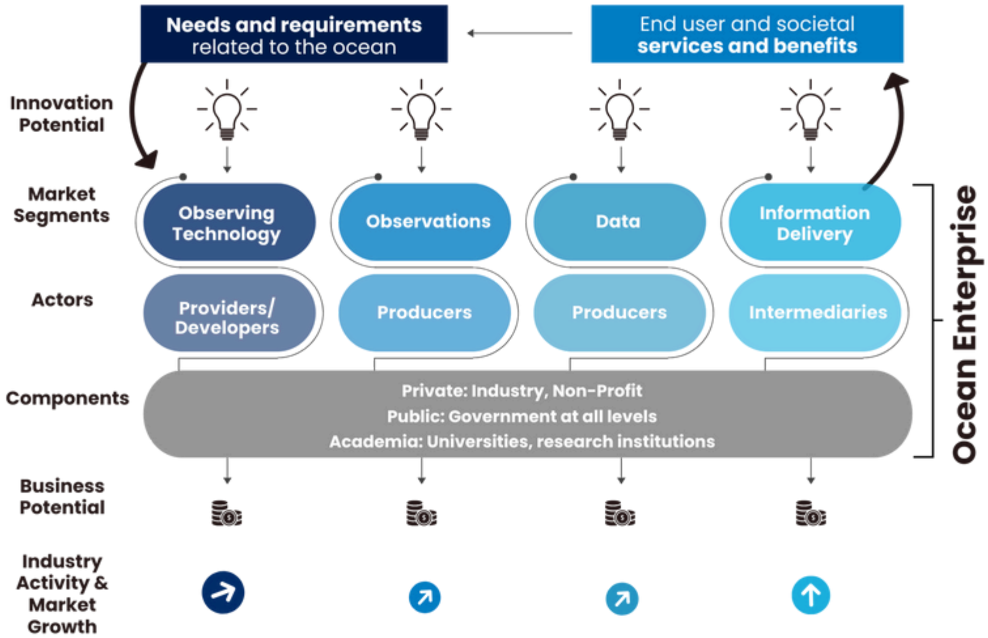

Figure 1: *This graphic visualizes the Ocean Enterprise and its interconnected components and activities across the Ocean Information Value Chain. The Industry Activity & Market Growth discs visualize the current level of private industry involvement in the segment, i.e. they offer an estimate of the current relative market size. The arrows indicate our estimate of private industry growth potential in each area (vertical is high). All market segments can benefit from innovation and can be commercially exploited. This graphic was developed as a product of the Dialogue with Industry Roadmap.*

The *Dialogues* are market-driven discussions in which technical and scientific issues are addressed in the context of market dynamics. The objective of the *Dialogues* is to develop actionable pathways that the Ocean Enterprise can implement to advance the democratization of ocean observation.

The third *Dialogues* featured three discussions on market dynamics to improve collaborations among public, private, and academic sectors. Their goal is to make actionable ocean data more accessible. This paper reviews terminology, concepts, challenges, and opportunities in future ocean observation, including infrastructure, sensors, platforms, and accessibility.
The third *Dialogues* supports the following challenges of the Roadmap:

- Market Visibility: Understanding the viability of an "accessible" ocean technology and/or "low cost" sensor market and how they will be used in complement to the existing sensors and technologies.
- Aggregation of Demand: Assessing key customer segments, evaluating market feasibility, and identifying challenges that must be addressed to accelerate market growth.
- Emerging Technologies: Determining which enablers, infrastructures, and technologies have the potential to lower the cost of ocean observing by one to two magnitudes.
- Public-Private Exchange: Fostering active engagement to increase global reach.
- Public and Private Data Access: Exploring access to privately collected data.

Overall Challenge

Traditionally, ocean observing technologies have aimed for high precision and accuracy to capture the complexity of ocean conditions, monitor changes over time, and be designed to withstand the harsh conditions under which they operate. This results in a cost point that is not accessible to all and may not be the optimal pathway to fulfilling the societal requirements for ocean observing. This, among other limitations, creates geographic regions that are under-observed or unexplored, resulting in data-sparse regions that are often essential to understanding complex ocean processes.

Despite rapidly expanding demand for ocean information to understand the complexities of the ocean and its impacts on society, there has been no significant increase in observations over the last five years, according to the Intergovernmental Oceanographic Commission (IOC) State of the Ocean Report 2024. Although nations need to invest more in this critical ocean observing infrastructure, they also need to examine the most efficient pathways to expand ocean observing, including how we acquire and use the most fit-for-purpose technologies.

Although many communities develop and manage observing systems and plans, these are typically guided by scientific inquiry rather than societal demand, resulting in inconsistencies, limited data accessibility, and a lack of sustained funding for observations. It is expensive and logistically unfeasible to achieve the level of ocean information that society needs without improvements across the entire Ocean Information Value Chain. The ocean observing community has expanded, with greater private sector involvement. Coupled with advancements in electronics, sensor technology, platforms, signal processing, data handling, and materials, as well as streamlined processes, we can now revisit the foundational aspects of ocean observation.

The World Meteorological Organization (WMO) has identified primary application areas for marine forecasting and real-time monitoring; disaster risk reduction (including marine hazards); marine environmental emergency response; coastal and offshore services; and ocean biogeochemical cycles. A business case for funding ocean observation at the necessary spatial and temporal resolutions has not been presented. While we need to continue making the case for sustained funding, the Ocean Enterprise considers it equally important to define a future that incorporates different sensors, platforms, enablers, and processes to decrease the overall cost of ocean information and broaden accessibility. We recognize that across all ocean-observing technologies, there is a desire to make the collection and translation of this data into usable information more efficient. Several consortia have been discussing how to increase global access to ocean observation technologies, referring to these efforts as “accessible” and/or “low-cost” ocean technologies (See Appendix 1). This dialogue series focuses on providing context for these ocean observation technologies and sensors and on how they can operate alongside our current methods of ocean observation, thereby enabling more comprehensive ocean observation.

In planning the third *Dialogues,* we asked what defines an “accessible” and/or “low-cost” ocean technology and sensors. Even defining the terms is difficult. We have proposed some alternatives in the terminology section and will discuss them throughout the dialogues. We will explore what makes ocean technology more efficient and how ocean information has the potential to disrupt existing markets, creating opportunities to increase sustainability while building consumer and product value.

Trends Within the Ocean Information Value Chain

1. High-bandwidth satellite data transmission / communications
2. System-on-a-Chip, Lab-on-a-Chip (LoC), miniaturization
3. Energy harvesting technologies and energy efficiency
4. Artificial Intelligence (AI), Machine (ML) Deep Learning (DL) Edge processing
5. Antifouling Coatings and Robust Encapsulation
6. Atom-based sensors e.g., quantum sensors
7. Low-power wireless communications
8. FAIR and CARE data sharing, Cloud storage and data sharing
9. Citizen science and Community Contributions
10. Industrial, higher-efficiency, larger unit number production
11. Repairability, Right to Repair, Calibration, Maintenance
12. Real time data or information products/output
13. Data collection as a service / Commercial Ocean Observing
14. Advanced materials, nano materials for sensitivity and durability, biosensors
15. Highly autonomous platforms (e.g., long-term deployments, navigation)
16. Digital twins, advanced modelling and simulations, predictive maintenance
17. Best practices, Common protocols, Consolidated and harmonized understanding of measurements
18. Open source and community support
19. User-friendliness and smarter software
20. Environmental footprint, Sustainability

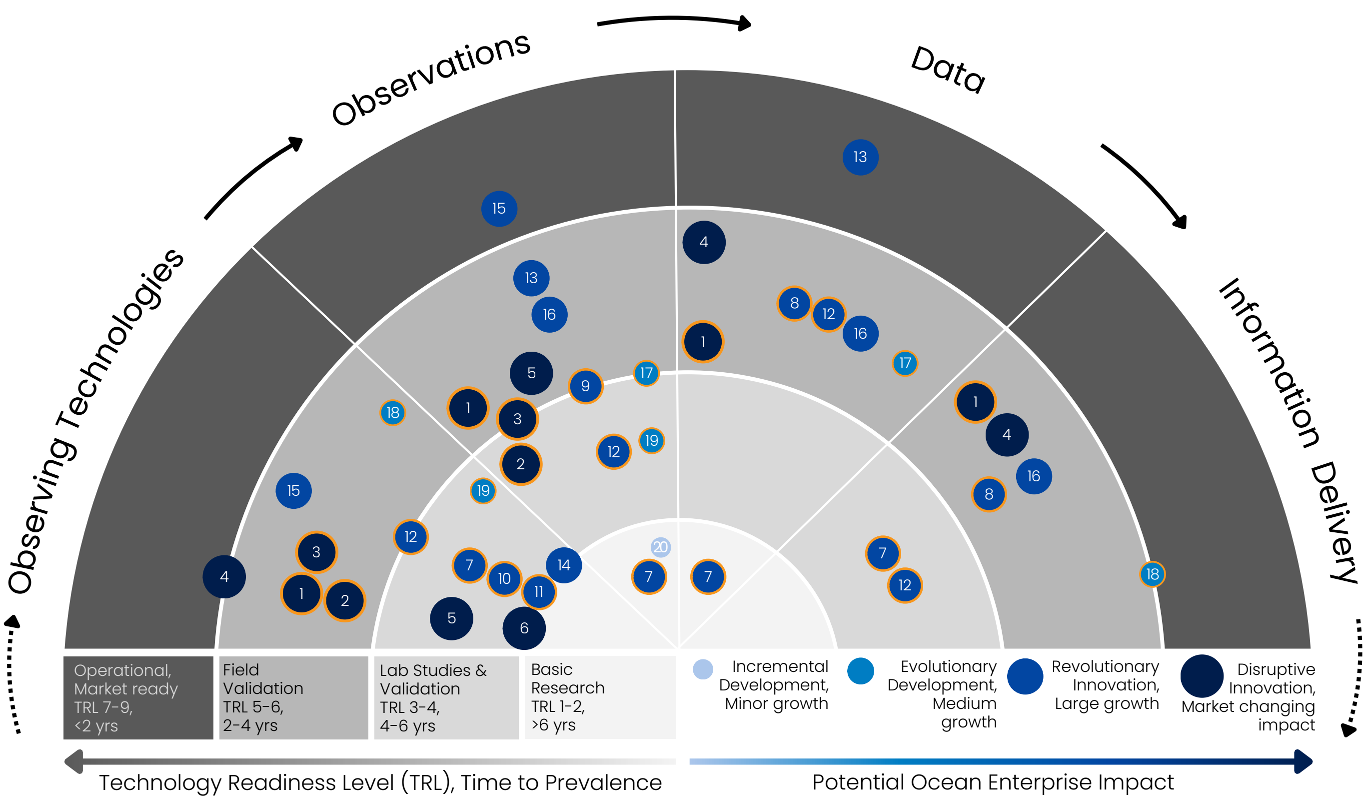

Figure 2: Radar chart showing the readiness levels and time to prevalence as well as potential impacts on the global Ocean Enterprise of trends, enablers, infrastructure, and emerging technologies of the Ocean Information Value Chain. Those outlined in orange specifically enable accessible ocean observing technologies.

A multitude of technological advancements and enablers have continuously improved and disrupted the Ocean Enterprise. In Figure 2, we mapped the prevailing trends, along with estimates of technological readiness, time to prevalence, and their potential impact on the Ocean Enterprise across the Ocean Information Value Chain (Figure 1). The center of the diagram represents lower technological readiness and a longer time before a market impact can be expected. The radially longer the distance, the more mature the trend and the shorter the expected time to full impact. The potential impact of a trend is depicted by the point size. Some trends appear in more than one market segment.

The largest number of trends is found within the first market segment, “Observing Technologies,” and decreases as the value chain progresses. While this could be a bias stemming from the authors' "observing technologies" perspective, it could also reflect a real indication of where and how innovation is currently happening in the field. In fact, this pattern is inversely comparable to the “private industry growth potential” as indicated by the arrows in Figure 1. Most changes are expected to follow trends anticipated over the next 2-6 years. Sixty percent of the trends enable and impact accessible ocean observing technology. Half of the trends qualify as revolutionary innovations supporting large organic growth, while 30% have the potential for disruptive innovation with a market-changing impact. The trends are further discussed below in the section ‘Emerging Technologies, Enablers, and Infrastructure.

Figure 2 aims to illustrate the current innovation landscape and stimulate a fruitful discussion within the Dialogues. Especially changes in societal perception and appreciation for ocean-related information linked to political action can accelerate the timelines presented or delay progress over the next 6 years (the ongoing United Nations Decade of Ocean Science for Sustainable Development 2021-2030).

Over the last 20 years, the majority of ocean observing has been funded by public institutions. Over the past five years, private sector involvement—both for-profit and non-profit—has grown through the development of sensors and platforms, funding innovation, and exploring new business models. However, as this is a fledgling and costly market, limited sensor purchases hinder commercial viability.

Key Concepts to Facilitate Effective Dialogues

This section briefly introduces some terminology and key concepts as a basis for describing, discussing, navigating, and advancing this changing market landscape.

Terminology

Definitions within the Ocean Enterprise are not always consistent. Below, we define several terms to guide the discussion and ensure consistency throughout the Dialogues. The first 7 definitions are taken from community references or are the consensus of the planning team and will not be discussed during the *Dialogues*. The final two terms, *Accessible Ocean Technologies* and *Low-Cost Sensors*, were discussed during the third Dialogues.

Ocean Enterprise

All entities in the public, private, non-profit, research, and academic sectors that provide infrastructure and capacity of ocean observations, measurement, and forecasting, or who deliver operational ocean information projects and services. (Roadmap)

Downstream Services

Applications and services that utilize the freely available data and information provided by public ocean observing networks. Value added ocean information services supporting societal and economic benefits. (Adopted from Copernicus)

Ocean Observing Sensor

A device for measurements that translates the output quantity from a transducer and converts it into a signal. The transducer is the “sensing element” of the sensor that is directly affected by the phenomenon, and which provides an output quantity characterized by a specified relation to the input quantity. Sensors can measure physical, chemical, and biological properties. (ISO 22013:2021 - Marine environment sensor performance — Specifications, testing and reporting — General requirements)

Ocean Observing Instrument

The device deployed into the water that includes one or more sensors, along with additional components such as the pressure housing, data capture, and communications.

Ocean Observing Platform

A host structure or carrier that positions sensors and instruments spatial-temporarily to monitor the ocean. They include satellite, buoys, fixed points, drifters, research vessels, and all types of autonomous vehicles.

Scalable

Ability of a sensing system to grow or adapt across space, time, or deployment sites without significantly increasing cost or complexity.

Cost-Effective Sensors

Sensors that offer strong performance relative to their total cost of ownership (compared to the cost/benefit ratio of other similar sensors), considering not just purchase price but also long-term value, reliability, and efficiency.

These next two terms are not easily definable as they can vary from region to region and by parameter. The definitions do not consider the feasibility of achieving the numbers or magnitudes of reduction but offer a framework on how to discuss these terms. An aim of the dialogue is to reach a consensus on these terms to enable action pathways for achievement.

Accessible Ocean Technologies

A combination of sensor, instrument, and platform affordability in terms of cost, operations, and maintenance. An accessible sensor meets the same quality of the current technology for a given parameter but achieves a one order of magnitude cost differential compared to the status quo.

Low-Cost Ocean Technologies

A Combination of sensor, instrument, and platform affordability in terms of cost, deployment, operations, and maintenance. Low-cost sensors are defined as costing less than $1,000 USD and can be deployed in sufficient quantities to monitor rapidly changing areas where early warning is necessary. We note that, when stating a specific price, there are differences related to the observed parameters, while in general, there seems to be a perceived threshold linked to the desired wide applicability. Additionally, it may be defined by its cost-effectiveness, i.e., a sensor that achieves a two-magnitude reduction in cost compared to currently deployed sensors for a given parameter.

Deployment Areas and Geographic Scope

Traditionally, oceanographic sensors have been provided in rugged formats (i.e., Titanium or coated Aluminum housing) to enable successful, long-term deployments in the open ocean. Typically, they are either designed for surface water deployments or have depth capabilities of, e.g., ~100 m, 300 m, 1000 m, 3000 m, or 6000 m (i.e., full ocean depth'). Designing sensors for coastal applications (minding enhanced biofouling stress) can reduce complexity and hardware cost.

The third Dialogues do not focus on a specific geographical area but recognize disparities in ocean-observing sensors and platforms across the Global South and island nations.

Economics

Ocean environments are expected to continue undergoing and experiencing tremendous change. These changes are largely the consequence of human activity, which has altered many natural systems on which human life and human systems depend (IPCC 2013). Examples of these changes include ocean warming, ocean acidification, deoxygenation, habitat changes/destruction, and eutrophication (Lotze et al. 2019; Chai 2020). Sustaining human life and societal systems, such as human economic activities and business enterprises, will, in part, depend on how well we understand and adapt to these anticipated changes; and, to a great degree, how much additional risk and uncertainty we are willing to accept in our daily lives.

Mitigation and adaptation to these changes and the anticipated risks will also depend on how well we understand ocean data. This is especially true given the expected increases in extreme ocean weather events (Rhein et al. 2013). Here, sensors and platforms offer tremendous opportunities to gain critical insights to aid human decision-making and protect life. Moreover, recent tragic events in Texas, with a death toll of over 100 people due to flooding of the Guadalupe River (see Economist 2025), underpin the need to not only invest in sensing and monitoring but also invest in the interpretation, understanding, and dissemination of the generated data.

Sensors and platforms also produce opportunities for value creation, given the anticipated changes to the natural environment. Economic opportunities exist in both private and public spheres. From a societal perspective, sensors and platforms offer opportunities for government programs and policymakers to improve people's well-being locally, regionally, and globally. From early warning systems related to extreme weather occurrences, such as hurricane and tsunami detection and mitigation (Selva et al. 2021, Mori et al. 2022), to beach closures due to harmful algal blooms (Miao et al. 2016, Rome et al. 2022), sensors and platforms can advance and enhance life and can create tremendous net benefits to society.

From a private industry perspective, sensors and platforms have come a long way, with substantial improvements in materials and technologies, which ultimately resulted in and will continue to result in lower costs, increased performance, enhanced functionality, and improved user-friendliness, creating opportunities for businesses of any size to materialize. Given these recent cost reductions and efficiency improvements, markets are expected to provide opportunities to increase value on both the supply and demand sides (Rayner, 2021). Additionally, and perhaps most compelling, we are likely not yet aware of the numerous economic opportunities that will arise with new sensing technologies and through a significantly increased number of sensors in the field. This creates opportunities for entrepreneurship but also places a responsibility on governments to increase investments in supporting and advancing sensing technologies, for example, through federal grant programs and subsidies.

Lastly, a new generation of low-cost sensors has substantially reduced market-entry barriers for some parameters and applications, providing opportunities for both governments and private industry. Building economic momentum based on these sensors and platforms will be a key element of the third Dialogues.

Finance

Global oceans are a primary driver in regulating the Earth's climate, sequestering about 30% of all carbon emissions (United Nations 2025a), and providing ecosystems and fish habitats that supply about 15% of all human animal protein (UN Department of Economic and Social Affairs 2022). Moreover, over 80% of globally traded goods and services are transported by sea, and rapidly growing economies tied to global oceans support the livelihoods of 3 billion people worldwide. Approximately 80% of global tourism takes place in coastal areas, and ocean fisheries support around 57 million jobs (UN Trade and Development, 2024). Ocean sensors and platforms will play an increasingly significant role in data generation, advancing the Ocean Enterprise as a whole and stimulating economic growth. Given the expressed need for ocean sensors and platforms, important questions concerning the funding vehicle remain. The annual costs of ocean conservation are estimated to be approximately US$174 billion (Thompson 2022, Allianz Research 2024); however, current funding models worldwide fall short of addressing these needs (Bos et al. 2015, Thompson 2024). Much of the financial burden currently falls on philanthropists or governments (Evans et al. 2012), particularly for higher-risk projects (Thompson et al. 2022). On a global scale, it is estimated that the conservation funding gap amounts to approximately US$7 trillion per year. Thus, additional funding mechanisms are needed to address these shortcomings. Below, we briefly discuss a few of these and provide a reference for more details.

Blue Finance Models

Blue Bonds. Like green bonds, part of the sustainable and social bonds family, which have seen substantial growth in recent years (T. Rowe Price, 2024), blue bonds are financial instruments designed to generate both positive environmental impacts and financial returns. Blue bonds are typically designed for projects that address United Nations Sustainable Development Goal 14, "Life Below Water" (see United Nations 2025b for additional information), and more broadly, the Blue Economy (Thompson 2022). Ocean observation through sensors and platforms may be particularly well-suited for this type of funding, as they support critical data collection for sustainability while also generating profit-oriented data that benefits private industry. For an overview of Blue Bond lending and issuance, the World Bank has compiled a comprehensive practitioner's guide (World Bank 2025b).

Outcome-Based Finance. A performance-based tool that offers investors additional security, as funding availability is contingent on meeting environmental goals or other predetermined outcomes. Primarily targeted at blue carbon, plastic pollution, and biodiversity credits, this funding mechanism enhances incentive compatibility, thereby managing uncertainty and risk. Since payments are often tied to environmental performance, there are opportunities to bundle ocean observing sensors and platforms into conservation projects (see World Bank 2025c for additional insights).

Debt for Nature Swaps. An instrument that essentially exchanges debt for environmental conservation. The focus of these programs remains on conservation and environmental protection rather than debt relief, and they typically involve third-party or government oversight. They have been successfully implemented in several countries, such as Belize and the Bahamas (World Bank, 2025c). As with the other two funding vehicles, data generation through ocean observation is a critical need for monitoring.

Several other private and public funding tools exist and are primarily associated with ocean conservation (for a comprehensive guide, see World Bank 2025b and c; also see The Nature Conservancy 2023 and European Commission 2025). That said, all these funding vehicles rely on data to ensure that the given conservation goals are met. Ocean observing sensors and platforms will play a critical role in meeting conservation goals while also generating opportunities for private profit.

Emerging Technologies, Enablers, Infrastructure

Across the Ocean Information Value Chain, hardware, software, and processes can improve measurement efficiency and reduce measurement costs (Figure 2). It is essential to identify where improvements can have the greatest impact on data collection costs. Some regions of the world with less developed ocean-observing systems are exploring technologies and processes to rapidly address rising regional needs. An analogy is the telecommunications business, where wireless technologies have enabled many regions to modernize without the need for landlines and associated infrastructure. To achieve evenly distributed measurements across the world's oceans, considerations must extend beyond sensor costs to include effective knowledge transfer, active collaboration between developed and developing nations, and strategies for disseminating technology to less developed countries. What processes can be applied to make the existing sensors and associated costs more efficient, thereby lowering the cost of measurement?

The following table provides further information on the enablers, infrastructure improvements, and emerging technologies of the Trends Within the Ocean Information Value Chain depicted in Figure 2.

Enablers			
# from Figure 2	**Trend**	**Description/Benefit**	**Examples**
3	Energy harvesting technologies and energy efficiency	Self-powered sensors and instruments extend deployment durations and operational lifespan, reduce the need for external power, and improve reliability and cost-effectiveness. Overcoming power availability as the limiting factor for in situ measurements.	Piezoelectric materials, wave energy converters, thermal gradients and solar-powered sensors.
4	Artificial Intelligence (AI), Machine Learning (ML), Deep Learning (DL) and edge processing	Enhances data processing, pattern recognition, predictive capabilities; analyzes large datasets, identifies trends, optimizes observation strategies. Local data processing reduces the need for constant connectivity, optimizes bandwidth, enables real-time analysis and decision-making at sensor level.	Predicts extreme weather events, automated anomaly detection, image processing for species identification and habitat mapping. Immediate responses minimize data transmission costs, and continuous operation in remote environments.
9	Citizen Science and community contributions	Engages local communities in data collection, observation, and analysis, increasing coverage at low cost; supports science education, public awareness, stewardship; and supplements scientific data.	Ships of opportunity e.g fishing vessels, sailing craft, recreational boating integrating ocean observing technologies.
11	Repairability, Right to Repair, Calibration, Maintenance	This allows for easy replacement of damaged components, enhancing usability and reducing maintenance costs. User-enabled re-calibration and maintenance functionalities by design. Decentralized maintenance is needed through local contracts or enhanced training for owners.	Modular sensor designs and standardized components facilitate quick repairs and upgrades.
16	Digital Twins, advanced modeling and simulations, predictive maintenance	High-resolution, multi-dimensional, near real-time virtual representation of the ocean or component of it; uses real-time and historical data to simulate future scenarios and address "what-if"-questions.	Digital representation of real-world entities or processes. Digital representation of marine ecosystems to predict environmental changes and plan resource management strategies.

# from Figure 2	Trend	Description/Benefit	Examples
17	Best practices, common protocols, consolidated and measurands	Further development of the ocean enterprise requires interoperability and common approaches, from sensor operation (e.g., calibration procedures) to data handling (e.g., metadata requirements). This is an enabler and pre-requisite for work with the data further down the value chain, i.e. the preparation of information products from the data.	The Intergovernmental Oceanographic Commission (IOC's) Ocean Best Practices System (OBPS) is a comprehensive framework that consolidates best practices, protocols, and standards for oceanographic measurements and data handling. This system ensures interoperability and standardized approaches across global ocean observation projects.; Essential Ocean Variables (EOVs).
18	Open Source and community support	Sensors, platforms and analysis software developed as open source solutions foster innovation.	Further development of solutions and user support is provided by the community rather than a single manufacturer. Involving locals helps ensure observation networks match regional needs and encourages data-driven environmental management.
19	Enhanced user-friendliness and smarter software	Ensure non-experts can use the sensors and obtain helpful data/information output.	Enables larger user groups for sensors beyond specialists. User-friendly interfaces and automated data interpretation tools enable larger user groups for sensors beyond specialists.

Infrastructure Improvements			
# from Figure 2	**Trend**	**Description/Benefit**	**Examples**
1	High-bandwidth satellite data transmission / communications	Reliable data transmission ensures connectivity with minimal latency globally.	Low-Earth orbit (LEO) satellites, LoRa Direct to Satellite (DtS), Starlink.
7	Low-power wireless communication	Efficient long-range data transmission enhances connectivity without the need for gateway technology.	LoRa (Long Range) and LoRaWAN (Wide Area Network) technologies to provide efficient, low-power, long-range data transmission. This enhances connectivity in remote maritime regions without the need for traditional gateway technology.
8	FAIR and CARE data sharing, cloud storage and data sharing	Guidelines that make data FAIR (Findable, Accessible, Interoperable, Reusable) and addressing CARE demands (Collective benefit, Authority to control, Responsibility, Ethics).	Public sector data accessibility at no cost, complemented by ethical aspects and societal demands.
10	Industrial higher-efficiency, larger unit number production	Larger quantity production leverages industrial efficiency gains, lowering the cost of manufacture and simplifying logistics.	Potential for faster production, reduced product costs, and consortium buying.
12	Real-time data or information products / outputs	Future innovations will be born from combining technologies and trends. Data processing advancements combined with enhanced connectivity enable applicable information output.	Real-time environmental monitoring systems provide instant data for decision-making. For example, smart buoys are equipped with edge processing capabilities and connected to LoRaWAN or high-bandwidth satellite transmission.
20	Environmental footprint, Sustainability	Address environmental concerns such as material debris and ensure new technologies are used sustainably with minimal environmental footprint.	Energy harvesting systems, recoverable technologies, biodegradable materials.

Emerging Technologies			
# from Figure 2	**Trend**	**Description/Benefit**	**Examples**
2	System-on-a-Chip (SoC), Lab-on-a-Chip (LoC), miniaturization	Integrates multiple sensor functions, reduces size, cost, and power consumption, allows for high unit number production, and enables large-scale deployment.	Compact, efficient sensors extending operational lifespan, enabling sensor redundancy.
5	Antifouling coatings and robust encapsulation	Prevents biofouling and corrosion, extending deployment durations and sensor lifespan.	Improves durability in harsh marine environments.
6	Atom-based sensors e.g., quantum sensors	Utilizes quantum properties for sensitive measurements, enables precise navigation and detection of environmental changes.	Ultra-accurate positioning, GPS-free navigation, multi-modal sensing with high sensitivity and accuracy for environmental monitoring.
13	Data collection as a service / commercial ocean observing	Business model where a private entity offers either data or mission as a service or operates an ocean observing network.	Existing companies have started offering this service.
14	Advanced materials, nano materials for sensitivity and durability, biosensors	Enhances sensitivity and durability, detects trace elements and pollutants, improves resistance to biofouling and corrosion.	Graphene, nanocomposites, biosensors for water quality and algal blooms.
15	Highly autonomous platforms (e.g. long-term deployments, navigation)	More autonomous, easier to use, highly maneuverable, long-range, deployable for weeks-months, increased sensor integration.	Autonomous underwater vehicles (AUVs), long-endurance unmanned surface vehicles (USVs), offering weeks to months of deployment for complex missions.

Advancements in Sensors and Platforms: Reducing Costs and Increasing Utility

A core question is whether a decrease in the cost of ocean sensors and platforms is feasible and, if so, under what circumstances. Understanding the key barriers and limitations to reduced costs and other access barriers to common ocean technologies is a focus of this Dialogues. The prices of many instruments and platforms have not been significantly reduced recently; however, other factors, including improved performance, increased capability, more powerful platforms, more sophisticated sensors, and longer-duration platforms, should be considered in this context. It's essential to evaluate whether reducing prices by one or two orders of magnitude is feasible and to comprehend the associated obstacles.

There is a perception that low cost implies less performance or quality. Is this an accurate statement? Are there areas where “lower quality” observations are allowable? Do all observations have to be at the highest standard?

Reducing Access Barriers

There is a growing need for high-density ocean sensors in distributed networks to provide accurate, real-time data for validating and enhancing the performance of numerical forecasts and for early warning systems. Multi-disciplinary collaboration is essential for understanding the linked ecological, biogeochemical, and physical processes in, especially, coastal systems. Coordinated efforts from oceanographers, geologists, ecologists, and social scientists are needed to develop integrated monitoring strategies for these dynamic environments. Observing capabilities are not equally distributed, as noted in the Ocean Decade Vision White Papers – Challenge 7: Sustainably expand the Global Ocean Observing System, the Co-authors of the OceanObs19 white papers were affiliated mostly with European (42%) and North American (37%) organisations, with 8% affiliated to Oceanian, 8% to Asian, 3% to South American, and 2% to African organisations showing the global imbalance in ocean observing capacity. A key recommendation of that report:

> *“Upgrade and expand ocean observing capacity in poorly-observed areas such as polar regions, island nations and territories, coastal areas of developing nations, coastal systems that are rapidly changing, and the under-observed deep ocean. Thematic priorities for ocean observing by 2030 should focus on key climate risk and adaptation needs, extreme events, coastal services for ocean management, ocean carbon, marine pollution, biogeochemistry, and biodiversity.”*

Business Case and Market Maturity

The authors propose the following: A mature Ocean Enterprise is characterized by a 10-fold increase in both public and private investment in long-term ocean observation, as well as recognition that the ocean technology and information market contributes to a country's gross national product.

Organizations like the OECD use industry codes to monitor ocean and blue economy trends, but these statistics often overlook the OE business sector. Survey-based studies in the USA, Canada, and the UK report an annual revenue of €12.1 billion (2000-2025), highlighting the sector's significance for investment and economic activity. As the Ocean Enterprise matures, it benefits developers of observing technology, ocean data producers, intermediaries, and the broader society through sustained public/private partnerships in ocean observation. The studies further show an increase in the number of companies. Canada's Ocean Enterprise 2024 study reveals that the number of companies increased by 31% from 160 in 2022 to 209 in 2024, mirroring the growth observed between 2020 and 2022. While this trend is positive, in Canada, much of the funding remains in the form of grants for public projects. The studies distinguish between producers and intermediaries and provide some information on company size, but they do not examine technology costs. They also cover only three countries and offer no insights into whether there is a market for accessible or low-cost technologies and sensors, how mature that market is compared to existing sensors, or its overall scale. Is the accessible sensor market competing directly with 'standard' sensors, or is it more specialized in its approach? How large could this segment become? Will revenues split evenly between 'standard' and accessible sensors, or will accessible sensors remain a smaller share, for example, 15% of the market? While less developed regions need lower-cost tools, everyone can benefit from them. Open dialogue is crucial for the Ocean Enterprise to collaborate on advancing the affordability and capabilities of ocean technology.

Market Challenges

Challenge 1: Several investors regard the accessible/low-cost market as being limited and are unwilling to invest.

Challenge 2: There have been some investments by philanthropists such as Schmidt Ocean Institute or Inkfish. What attracts these entities to invest? What strategies might attract additional investors?

Challenge 3: Groups discussing accessible sensors have learned that venture capital firms tend to favor high-impact technologies over low-cost or broadly accessible ones. What methods might be employed to better align proposals with these interests?

Challenge 4: Research institutions and universities continue to develop their own sensors because they can't find a sensor produced by a commercial vendor, the technology is too costly, they have limited funding for direct purchases, or they receive funding more easily for development than for purchases. Other barriers include restricted funds for validation at central hubs. Is this due to poor communication or an underdeveloped market? Does public research funding promote or hinder innovation in ocean sensor markets over time? For the Ocean Enterprise, is it beneficial to develop solutions tailored to local needs?

Challenge 5: How can we ensure quality control, facilitate commercialization, lower production costs, and guarantee lifecycle support?

Challenge 6: Typically, sensor pricing is more influenced by production costs than by market affordability. Are there alternative pricing models, such as those used in the pharmaceutical sector, where prices are adjusted according to a country's ability to pay?

Challenge 7: The significance of data is sometimes not considered sufficient to justify funding. This could relate to gaps in education or perceptions of market risk. For instance, with vaccines, the perceived value may not increase until herd immunity is demonstrated through widespread use. To address this, providing clear examples of how a higher concentration of sensors in a particular area improves data quality and resolution—especially when using lower-cost sensors in complex ocean environments—may help illustrate the benefits and clarify the value proposition.

Value Creation: Data Dichotomy

There are two aspects to the data "dichotomy." The first is that if ocean sensing is too expensive, then the data and subsequent information are not valuable enough to society. This raises the question of how society can be persuaded of value and merit.

The public expects data to follow FAIR and CARE sharing principles—guidelines that make data findable, accessible, interoperable, and reusable. This is often interpreted as allowing free use of publicly sourced data, but actual usage depends on local regulations. For example, NOAA (United States) makes all publicly funded data freely available, including for commercial purposes, to support a commercial Weather and Ocean Enterprise. However, FAIR compliance does not automatically grant unrestricted access to everyone.

Blue economy companies are emerging, viewing data as a commodity and aiming to expand the market for ocean-related data and services. The challenge is to align this approach with FAIR principles. But questions remain, such as where does the private sector see value in the data? Have companies developed business models that are profitable in selling data while still sharing it with the scientific community at an affordable or no cost? The public and private sectors in remote sensing have addressed this issue through a licensing schema, in which different pricing scales apply to user types, timeframes, and the manner in which the data will be shared.

The Ocean Decade – Industry Sharing Committee – has been evaluating access to data collected by the private sector, or currently being collected. These efforts have shown some incentives for sharing the data in accordance with FAIR principles and at no cost:

- Ancillary data to the primary mission is not proprietary
- Desire by company personnel to be part of a larger cause

Limitations include the extra cost of formatting data to adhere to FAIR principles and the cost of maintaining and providing access.

Acknowledgement

The third Dialogues, along with the background paper and use cases, are being developed under the Ocean Enterprise Initiative. The authors and the core organizing committee members would like to express their sincere gratitude to all participants and observers of the Dialogues with Industry initiative. MTS efforts identified in this report are largely funded by the Department of Commerce NOAA grant, in support of the Ocean Observing Community Engagement Framework Cooperative Agreement detailed in NA23NOS0120322.

Sector	Affiliation	Name
Academia	Stanford University	Collin John-Erik Closek
Intergovernmental	GOOS	Patrick Gorringe
Intergovernmental	GOOS	Emma Heslop
Private/For Profit	Kongsberg Discovery	Peer Fietzek
Private/For Profit and Not for Profit	L3Harris/MTS	Donna Kocak
Public	NOAA/GOMO/UCAR	Ann-Christine Zinkann
Public	NOAA/IOOS	Zack Baize
Public	South African Environmental Observation Network (SAEON)	Juliet Hermes
Private/Not for Profit	Euro-Mediterranean Center on Climate Change (CMCC) Foundation	Viviana Piermattei
Private/Not for Profit	MTS	Hans VanSumeren
Private/Not for Profit	MTS	Caisey Myers
Private/Not for Profit	MTS	Hadley Clark
Private/Not for Profit	MTS	Zdenka Willis
Private/Not for Profit	MTS	Maik Kecinski

Appendix 1: Projects Related to Accessible Ocean Technologies

Accessible Ocean Technology (AOT) Community: A global community of developers, scientists, and practitioners who are working together to advance the field of cost-efficient and easier to use technology, deploy, and interpret resulting data. This community has been supported by its members and by funding from multiple philanthropies, as well as by coordination efforts from the Synchro, Deep Ocean Observing Strategy, Center for Ocean Solutions, AquaVela, Solutions Cost-Effective Ocean Observation Platform (SCOOP), and CoastPredict.

CS-MACH1: Horizon Europe project CS-MACH1 (MArine Citizen science data Horizon) (June 2025 - November 2027) aims to overcome existing barriers to citizen science empowerment, such as accessibility, recognition, trust, and sharing of marine citizen science data, by establishing and managing a Marine Citizen Science Data Network (MCSDN) of and for citizen science initiatives, community representatives, cost-efficient technology developers, data management experts, and scientists. https://www.seascapebelgium.be/cs-mach1

LandSeaLot: The 20-partner consortium aims to bring together fragmented land-sea interface area observation communities across various scientific domains to co-design and develop an integrated, optimal, and robust observation system for the land-sea interface area during February 2024 to January 2028. https://landsealot.eu/

NAUTILOS: Horizon 2020 Innovation Action project funded under the EU's Future of Seas and Oceans Flagship Initiative from 2020 to 2025, aimed to fill in marine observation and modelling gaps for biogeochemical, biological, and deep ocean physics essential ocean variables and micro-/nano-plastics, by developing a new generation of cost-effective sensors and samplers, their integration within observing platforms, and deployment in large-scale demonstrations in European seas. https://nautilos-h2020.eu/

OPENMODS: "To devise ocean sensors and monitoring devices, globally available to all and not just to a privileged few." In order to inform decision-making at all levels, from international economic and environmental policy down to small ocean-based businesses, such as fishing and tourism, scientists need access to more reliable and comprehensive ocean observation data. This 3-phased project ran from 2019 through 2024. https://pogo-ocean.org/innovation-in-ocean-observing/activities/openmods-open-access-marine-observation-devices/

Synchro: Synchro accelerates technological solutions for ocean research. It achieves this by providing a testbed for previously developed technology and by involving resource managers and other users who will ultimately use the technology in its evaluation process. By involving these decision managers from the beginning, we synchronize technology testing in real-world conditions, leading to quicker adoption of the critical tools needed to measure a rapidly changing ocean. https://oceansynchro.io/

TechOceanS: A European Union's Horizon 2020 program, the TechOceanS project advanced ocean sensing technologies, creating cutting-edge tools focusing on new materials, miniaturization and lower the cost. The program began October 2020 and concluded in September 2024. https://techoceans.eu/

Appendix 2: References

A., 2020. Monitoring ocean biogeochemistry with autonomous platforms. *Nature Reviews Earth and Environment*, *1*(6), pp.315-326.

Allianz Research. 2024. Sustainable Ocean. Accessed on August 03, 2025 at: https://www.allianz-trade.com/content/dam/onemarketing/aztrade/allianz-trade_com/en_gl/erd/publications/pdf/2024-07-30-oceans-AZT.pdf

Bos, M., Pressey, R.L. and Stoeckl, N., 2015. Marine conservation finance: The need for and scope of an emerging field. *Ocean & Coastal Management*, *114*, pp.116-128.

Evans, D.M., Barnard, P., Koh, L.P., Chapman, C.A., Altwegg, R., Garner, T.W.J., Gompper, M.E., Gordon, I.J., Katzner, T.E. and Pettorelli, N., 2012. Funding nature conservation: who pays?. *Animal Conservation*, *15*(3), pp.215-216.

European Commission. 2025. Mission Ocean and Water Service Portal. Accessed on August 4, 2025, https://projects.research-and-innovation.ec.europa.eu/en/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/restore-our-ocean-and-waters/blue-bond

Heslop, E., Willis, Z., Fietzek, P., Croll, B., Heupel, M., Kelly-Gerreyn, B., Rayner, R., Venkatesan, R. (2022). Dialogues with Industry Background Paper v.1. (Report no. GOOS-283 / MTS-202201)
Intergovernmental Panel on Climate Change. Climate Change 2013: the physical science basis (IPCC, 2013).

IOC-UNESCO. 2024. *State of the Ocean Report.* Paris, IOC-UNESCO. (IOC Technical Series, 190). https://doi.org/10.25607/4wbg-d349, State of the ocean report, 2024 - UNESCO Digital Library

Lotze, H.K., Tittensor, D.P., Bryndum-Buchholz, A., Eddy, T.D., Cheung, W.W., Galbraith, E.D., Barange, M., Barrier, N., Bianchi, D., Blanchard, J.L. and Bopp, L., 2019. Global ensemble projections reveal trophic amplification of ocean biomass declines with climate change. *Proceedings of the National Academy of Sciences*, *116*(26), pp.12907-12912.

Miao, H., Fooks, J.R., Guilfoos, T., Messer, K.D., Pradhanang, S.M., Suter, J.F., Trandafir, S. and Uchida, E., 2016. The impact of information on behavior under an ambient-based policy for regulating nonpoint source pollution. *Water Resources Research*, *52*(5), pp.3294-3308.

Mori, N., Satake, K., Cox, D., Goda, K., Catalan, P.A., Ho, T.C., Imamura, F., Tomiczek, T., Lynett, P., Miyashita, T. and Muhari, A., 2022. Giant tsunami monitoring, early warning and hazard assessment. *Nature Reviews Earth and Environment*, *3*(9), pp.557-572.

Rayner, R., 2021. Market analysis. In *Preparing a Workforce for the New Blue Economy* (pp. 113-134). Elsevier.

Rhein, M., S.R. Rintoul, S. Aoki, E. Campos, D. Chambers, R.A. Feely, S. Gulev, G.C. Johnson, S.A. Josey, A. Kostianoy, C. Mauritzen, D. Roemmich, L.D. Talley and F. Wang, 2013: Observations: Ocean. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V.Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Rome, M., Beighley, R.E. and Faber, T., 2021. Sensor-based detection of algal blooms for public health advisories and long-term monitoring. *Science of The Total Environment*, *767*, p.144984.

Selva, J., Lorito, S., Volpe, M., Romano, F., Tonini, R., Perfetti, P., Bernardi, F., Taroni, M., Scala, A., Babeyko, A. and Løvholt, F., 2021. Probabilistic tsunami forecasting for early warning. *Nature communications*, *12*(1), p.5677.

The Economist. 2025. Why was the flooding in Texas so deadly? Accessed on July 28, 2025 at https://www.economist.com.

The Nature Conservancy. 2023. Blue Bonds: An Audacious Plan to Save the World's Ocean. Accessed on August 04, 2025 at: https://www.nature.org/en-us/what-we-do/our-insights/perspectives/an-audacious-plan-to-save-the-worlds-oceans/

Thompson, B.S., 2022. Blue bonds for marine conservation and a sustainable ocean economy: Status, trends, and insights from green bonds. *Marine Policy*, *144*, p.105219.

Thompson, A., Bunds, K., Larson, L., Cutts, B. and Hipp, J.A., 2023. Paying for nature-based solutions: A review of funding and financing mechanisms for ecosystem services and their impacts on social equity. *Sustainable Development*, *31*(4), pp.1991-2066.

T. Rowe Price. 2024. Blue Bonds: A growing resource for sustainability financing. Accessed August 04, 2025, https://www.troweprice.com/content/dam/public/enterprise/insights/pdfs/2024/q2/ous/blue-bonds-a-growing-resource-for-sustainability-financing.pdf

United Nations. 2024. Trade and Development: Review of Maritime Transport 2024. Accessed on August 04, 2025 at: https://unctad.org/system/files/official-document/rmt2024overview_en.pdf.

United Nations. 2022. Department of Economic and Social Affairs: 5 reasons you should care about our ocean. Accessed on August 04, 2025 at: https://www.un.org/en/desa/5-reasons-you-should-care-about-our-ocean

United Nations. 2025b. Department of Economic and Social Affairs: The Sustainable Development Goals Report 2025. New York.

Willis, Z., Heslop, E., Fietzek, P., Kocak, D.M., Hodanbosi, M., Townsend, B., Smith, E.A., Baize, Z. (2024). Dialogues with Industry Roadmap (Report no. GOOS-294 / MTS-202401)

World Bank. 2025a. World's population will reach nearly 10 billion by 2025. Accessed on August 04, 2025, https://datatopics.worldbank.org/world-development-indicators/stories/world-population-will-continue-to-grow.html

World Bank. 2025b. Bonds to Finance the Sustainable Blue Economy. A Practitioner's Guide. Accessed on August 04, 2025, https://www.icmagroup.org/assets/documents/Sustainable-finance/Bonds-to-Finance-the-Sustainable-Blue-Economy-a-Practitioners-Guide-September-2023.pdf

World Bank. 2025c. Accelerating Blue Finance: Instrument, Case Studies, and Pathways to Scale. Accessed on August 04, 2025, https://documents1.worldbank.org/curated/en/099052925003028261/pdf/P180273-c31cabb1-1115-4cfa-9fda-4862ab3a6ecc.pdf

OCEAN ENTERPRISE INITIATIVE

Dialogues with Industry
Background Paper

Ocean Observing of the Future: Sensors, Instruments, Platforms and the Market Ahead

For bibliographical purposes, this publication should be cited as follows:

Fietzek, P., Kocak, D., Zinkann, A. C., Willis, Z., Closek, C. J. E. (2026) Dialogues with Industry - Ocean Observing of the Future: Sensors, Instruments, Platforms and the Market Ahead Background Paper.
(Report no. MTS-202506)

MTS marine technology society Opportunity runs deep™

GOOS Global Ocean Observing System

NOAA

IOOS Integrated Ocean Observing System