Building the Blue Innovation Pipeline

Lessons Learned from the United States and Sweden

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Institute for Sustainable Development

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Executive Summary

While there are many exciting innovations taking place in the "blue" (water-based) economy, the findings of this study indicate that more investment in research and development (R&D) is economically justified. In fact, blue R&D is underfunded by at least 112% compared to worldwide benchmarks. Even if an additional $30-50B (billion) in global funding for R&D reduced the future risks of water environments and increased the economic rewards of water-based industries by just 10%, this would still deliver $183B worth of economic benefit and enhanced environmental protection.

The case for innovative blue approaches to water management is clear. From a risk management perspective:

- Water-based natural disasters and other environmental impacts caused approximately $509.62B in global economic losses in 2022.
- Water-related disasters break down as follows: extreme storms (49%), floods (36%), and droughts (15%). Since 2000, flood-related disasters have increased by 134% and drought-related disasters by 29%.
- Other costs conservatively exceed $278B, including: ocean acidification ($10B), ocean plastics pollution ($8B), and poor sanitation and hygiene ($260B).
- These, in turn, create cascade effects for industries such as agriculture, aquaculture, finance, fishing, housing, infrastructure, and insurance.

Likewise, from an opportunity creation perspective, a study of fifteen maritime industries with total revenues of approximately $1.32T (trillion) as of 2022 illustrate three different types of market opportunities:

1. the reinvention of mature industries with low or declining growth rates like shipping, aquaculture, and fishing,
2. the embedding of blue features and benefits into high-growth industries like marine tourism, offshore wind power, container shipping, desalination, and deep-sea mining (DSM), and
3. the development of emerging maritime industries like carbon capture, utilization, and storage (CCUS), maritime digitization, unmanned underwater drones, and biomimetics.

Current blue R&D, including for off-shore energy, is $15.8B.

This amounts to 0.86% of 2022 total maritime revenues and environmental costs analyzed in this report combined. If this were increased to the global average of 2.5% for all R&D spending, this would represent a 300% increase on current global blue R&D budgets. If it were increased to leadership levels such as Sweden's of 3.5%, this would justify a 420% increase to $64.0B. To be clear, R&D is not necessarily correlated to funding levels, but more funding creates more opportunities for breakthroughs to happen.

A global increase of $30-50B in R&D would pay for itself, even if it only decreased water-related costs by 10% and increased markets by 10%. This level alone would lead to at least $183B worth of enhanced hazard mitigation, reduced disaster recovery costs, improved maritime market growth, and new job creation.

Both the United States (U.S.) and Sweden have developed significant water-based research and innovation clusters that help to explain the current state of blue environmental and economic progress. The U.S. has robust higher education programs across the states that border the Pacific, Atlantic, and Gulf Coast, as well as in the Great Lakes, Alaska, and Hawaii. These are supplemented by incubators and accelerators, specialized venture capital investors, and corporate business development ecosystems. Sweden's academic anchors are in Gothenburg, Stockholm, Norrköping, and Malmö. In addition, Sweden has sixty-four science parks and incubators located all over the country and robust western and eastern innovation ecosystems.

Over 71% of all water-based research in the U.S. and in Sweden is funded by the private sector. Public sector support, including European Union (EU) support, accounts for 25% in Sweden and 21% in the U.S. Higher education and private foundations account for the difference. 42% of all basic research is funded by government agencies, either directly or indirectly. Most private sector funding is directed towards applied research and experimental development.

Based on these findings, the following recommendations can help to catalyze more blue innovation.

Strengthen Research and Innovation Catalysts

- All sectors should develop catalytic tools to raise awareness about pressing research questions, both in terms of environmental challenges and market opportunities.
- Governments should create policy frameworks that incentivize private capital investment, innovation prizes, specialized journals, international conferences, education and workforce development programs, and other support systems for innovation pipelines.
- All sectors should consider developing catalytic incentives, such as the creation of prizes patterned after those like the Nobel Prize, competitions, hackathons, and so on.
- A blue innovation pipeline index should be developed that supports national:
    - needs identification and prioritization,
    - funding requirements versus budget,
    - basic research funding and productivity,
    - applied research,
    - experimental design,
    - entrepreneurship support and new business development, and
    - new product development.

Support Basic Research

- Governments should benchmark their current blue innovation R&D budgets and increase support for basic research to 50%, 75%, or 100% of best-in-class R&D funding levels. These investments should be indexed to projected costs and compound annual growth rate (CAGR) forecasts.
- Governments should not pick winners and losers, but rather, encourage competitions, diverse approaches, and multiple innovation hubs to flourish.
- Support must grow for drones, sensors and other monitors, and digital tools that can expand data coverage to measure essential variables related to

water dynamics and ocean processes across all sectors.

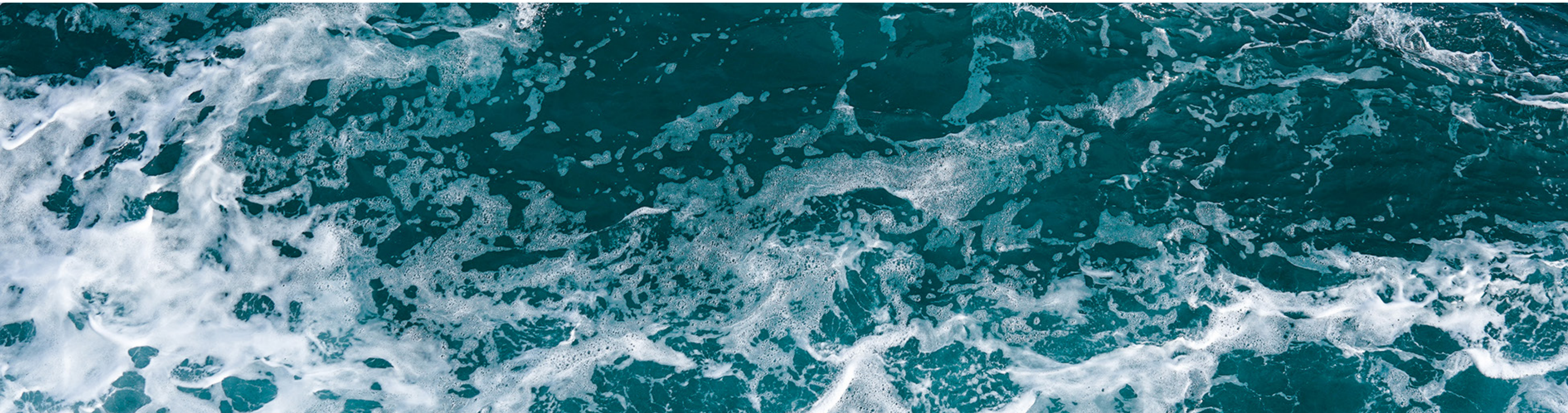
- Greater development is needed for new tracking and prediction capacities that support integrated and multi-hazard early warning systems, improved community preparedness, and greater awareness across all sectors.
- Efforts must advance towards building "digital twin" models of flooding, drought, and extreme storm conditions that leverage machine learning, artificial intelligence (AI), and the latest innovations in information technology that should be embraced across all sectors.

Strengthen Applied Research, Experimental Design, and New Business Development, specifically:

- the relationship and alignment between identification and prioritization of blue economy needs and public sector basic research investments,
- cross-sector and cross-industry dialogue, information-sharing, and network opportunities, and
- incubator and accelerator support systems and capabilities leveraging ports, industrial parks, research parks, and other facilities.
- After-action reviews and criticisms of existing approaches should by systematized across sectors. Catalysts for new ideas should be embraced in a spirit of promoting continuous improvement.
- "Failure" should be redefined as an important tool of the learning process, while "fast failure" that encourages pilots, prototypes, trials, and other initiatives that promote rapid learning should be embraced.

Build Up Pipeline Support Capabilities, specifically:

- encourage the development of water-themed educational materials for kindergarten through twelfth grade (K-12) curricula,
- support workforce development programs such as apprenticeships, community college and undergraduate programs, and advanced degree programming that includes financial support for students from lower-income or otherwise disadvantaged or underserved backgrounds,
- encourage corporate R&D, venture funds, and "intrapreneur" (new business developers inside large companies) programs,
- facilitate business, academia, and public sector dialogues, showcases, and information-sharing opportunities, and
- encourage private capital formation and deployment for water R&D. ●



The Purpose of This Report

The purpose of this report is to:

(1) discuss the current landscape for "blue" (water-based) innovation,

(2) identify potential areas for investment, collaboration, and future investigation, and

(3) identify innovation building blocks through the lens of United States (U.S.) and Swedish practices.

Our findings indicate that while blue innovation is relatively underfunded compared to the overall research and development (R&D) sector, there are many exciting initiatives, research projects, and start-ups underway that can be built on and encouraged.

For these reasons, the structure of the report is as follows:

This introductory section will discuss the importance of blue innovation, how it drives the blue economy, and what can be learned from the U.S. and Swedish innovation systems in order to make this strategy more systematic and effective.

Chapter 3 will briefly analyze some of the chief environmental risks posed by NOT investing more in innovative solutions, and at the same time, encourage interest in exciting research studies and start-ups that are already under way.

Chapter 4 will pivot and examine the future prospects for different maritime industries. They are certainly not all moving in lock step with each other. Some mature industries are in dire need of reinvention, while others are already engines of growth and job creation.

Having looked at the risks and rewards posed by water and the maritime industries, chapters 5 and 6 will capture lessons learned from both the U.S. and Swedish innovation systems.

Chapter 7 will identify recommendations that can systematize and expand on the blue innovation support systems that already exist and discuss how innovation can be developed as a central strategy for addressing water-based risks and expanding water-themed sustainable development.

THE BLUE ECONOMY

THE OCEAN ECONOMY

- Offshore Energy Production
- Oil and Gas Extraction
- Shipping and Ship-building
- Tourism

THE COASTAL ECONOMY

- Tourism
- Freshwater/Saltwater Fishing and Aquaculture
- Insurance
- Housing and Home Repair
- Flood/Storm Surge Management

THE WATER ECONOMY

- Effluents
- Hydraulics
- Hydroelectric Energy
- Lakes
- Rivers

What is the Blue Economy?

The term "blue economy" was introduced at the 2012 United Nations (UN) Conference on Sustainable Development to mean an ocean economy that aims for "the improvement of human well-being and social equity, while significantly reducing environmental risks and ecological scarcities[1]." It is vital to focus on the blue economy for innovation because the global private sector now accounts for two-thirds to three-quarters of all investment in R&D.

For the purposes of this report, the blue economy is differentiated from traditional maritime industries, in that participants in the blue economy incorporate environmental considerations as a part of their value proposition. This blue economy is growing alongside traditional industry approaches across every sector. The blue economy is commonly separated into three distinct categories: (1) the ocean economy, (2) the coastal economy, and (3) the water economy.

The ocean economy focuses on value creation on or below the ocean surface. The coastal economy focuses on the interface between water ecosystems and land ecosystems. Approximately 40% of the population in the U.S.[2] and 82% of the population in Sweden lives on a coast,[3] meaning that coastal industries such as shore replenishment, sea-level rise abatement, and coastal travel and tourism are increasingly significant. The water economy refers to industries related to lakes and rivers, as well as industries that utilize or manage water as a resource. For example, water treatment and flood management are two massive industries in the water economy subdivision of the blue economy.

Water industries have grown faster than the U.S. economy as a whole. In 2019, American maritime industries were responsible for $2.4-3.5M (million) jobs and contributed approximately $351-397B (billion) to the U.S. GDP, according to the National Atmospheric and Oceanic Administration (NOAA) and the U.S. Department of Commerce.[4,5] From 2018 to 2019, the U.S. blue economy grew at a rate of 4.2%.[6]

Since the U.S. accounts for 25% of the global market, this pegs the worldwide maritime sector at $1.6T (trillion). By 2030, the value of the global maritime sector is expected to reach $3-3.4T, with the most growth being seen in industries like tourism and offshore renewable energy. Of this total, industries and companies embracing blue principles expect to make significant gains in market share.

Why Focus on Blue Innovation?

When it comes to water management, the status quo is unsustainable. The World Meteorological Organization (WMO) and World Economic Forum (WEF) assert that the oceans are under threat like never before. The Council on Foreign Relations report that water stress is a global problem that is getting worse. Activists from Greta Thunberg to Alexandra Cousteau have complained about inaction, slow action, and worse. The economic costs of water-related disasters have skyrocketed in the past decade and reached $232B in 2022.

Innovation policy expands the pipeline of alternative solutions. This is vital because current trend lines in acidification, storm intensity, flooding, drought, biodiversity depletion, plastics pollution, and decarbonization are performing sub-optimally. Based on the Nationally Determined Contributions report, the Intergovernmental Panel on Climate Change (IPCC) reports that the earth may exceed the target

1.5-degree Celsius increase as early as 2030 and projects likely warming of 3-degrees Celsius or more.[7] Continuing business-as-usual will lead to perpetuating the same conditions that are already unsatisfactory.

On the flip side, the UN has proclaimed 2021 to 2030 a "Decade of Ocean Science for Sustainable Development." There are many fascinating developments taking place as marine exploration, new technologies, and better understandings open up water-based opportunities. The world water economy is expected to double by 2030, but some industries will grow at much faster rates than this. Blue innovation can spark better solutions and lead to better human interactions with the natural environment, while still generating economic rates of return.

For these reasons, innovation appeals to a range of stakeholders across the political spectrum. Fostering innovation is a core element of Sustainable Development Goal (SDG) 9, and it is also championed by hard-core capitalists. Environmentalists see business-as-usual as leading to unsustainable results. Both entrepreneurs and business change agents see economic opportunity. Change can help secure both future environmental security and broad-based prosperity. Quite simply, blue innovation could be a game-changer for the planet and for future wealth creation.

Be it figuring out ways to reduce acidification, lowering the energy consumption of desalination, or minimizing the environmental footprint of cruise lines, built-in markets exist for these solutions. How much would insurance companies or the state of Florida have paid to reduce the impact of Hurricane Ian?

For risk management, hazard mitigation, biodiversity,

Blue Innovation supports the following SDG goals:

and market development reasons, institutionalizing innovation must be a key driver for the advancement of the blue economy across all components of value creation.

Why Focus on the U.S. and Sweden?

Sweden has consistently ranked at or near the top of the world's most integrated green economies for the past five years, while the U.S. has had the largest green economy during this time span. Both countries have rich scientific cultures, robust entrepreneurial ecosystems, and a long track record of connecting basic science to promising new industries. These leadership positions also translate to the blue economy.

Sweden created the first-of-its-kind Ambassador for Oceans, Seas, and Freshwater and hosts the annual World Water Week. In December 2022, the Swedish Foundation for Strategic Environmental Research, or Mistra, jumpstarted a new round of interest in the blue economy when it announced that it would fund a new program called C2B2, or "Co-Creating Better Blue." The consortium behind C2B2 include many actors from the network around Ocean Data Factory Sweden and the Swedish Centre for Ocean Observing Technology.

The U.S. has multiple innovation clusters focused on cultivating the blue economy. In addition, the 2022 Inflation Reduction Act and infrastructure package approved by Congress have sparked a new round of interest in the overall green economy and the "blue-ing" of maritime industries.

Both countries are incentivizing the development of basic research and market solutions to achieve water-related environmental results. They have great pilots, projects, and programs that can be built on to advance future growth in innovation.

What are the Components of a Robust Innovation Pipeline?

The process of innovation is deceptively simple: generate ideas, convert ideas into productive outcomes, and then diffuse these ideas to key stakeholders and the public (Figure 1). Sometimes known as an "innovation chain," particularly for corporate leaders, an "innovation pipeline" has several component parts: the catalyst, basic research, applied research, experimental design, commercialization or public distribution, and scale (Figure 2). National innovation systems systematize pipelines anchored around different institutions or metro areas. This helps to promote a proliferation of ideas and approaches.

Innovation does not occur in a vacuum. Someone or some organization must set the agenda, frame the need, and prioritize focus. Catalysts start the cycle of innovation through idea generation – framing up a new approach, developing a critical insight, or discovering new facts that can lead to positive change.

"Innovation catalysts" include:

- Academia
- Authors
- U.S. Department of Defense (DOD) and international equivalents
- Policymakers
- Incubators and accelerators
- International organizations
- New business development
- Non-profit advocacy organizations
- Ports
- Think tanks
- Prizes and awards (e.g., the Ocean Observing Prize or the Nobel Prize)

Figure 1. The Innovation Pipeline

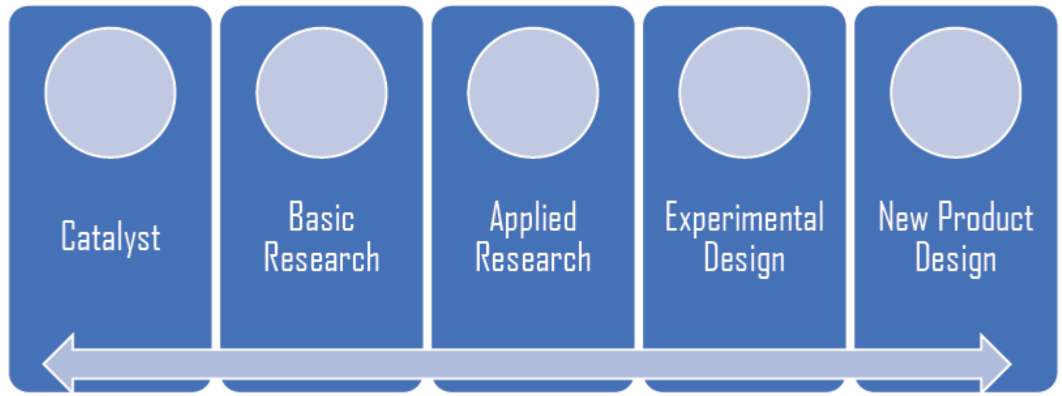


Figure 2. The Functions of the Innovation Pipeline

Examples of catalysts range from high profile figures, such as Greta Thunberg or Sylvia Earle, to mundane procurement requests for proposals and concept papers.

Catalysts inspire research. Via grants, subsidies, and other incentives, catalysts support the development of studies and pilots to explore ideas that have not previously been proven to be commercially viable. They lead through advocacy and by identifying problems or opportunities that inspire others. Catalysts are vital, as survey research indicates that the leading reason people do not do things is that no one asks them to do so.

For an innovation pipeline to increase the quantity and quality of outcomes derived from these types of research, a companion ecosystem must exist that accelerates praxis, or the conversion of ideas into actions. This is known as idea conversion, which has three core functions: (1) basic research, (2) applied research, and (3) experimental design.

BASIC RESEARCH, or fundamental research, is a type of investigation focused on improving the understanding of a particular phenomenon, study, or law of nature.[8] Such research is often theoretical and focused on the advancement of knowledge and the establishment of principles and/or formula to describe the phenomenon. It serves as a foundation upon which applied research can be grounded. The principal funders of this type of research are government agencies (42%) and foundations and academic institutions (21% combined). Businesses also fund approximately 30% of basic research projects.[9]

APPLIED RESEARCH is designed to solve practical problems and improve the human condition. Applied research might be focused on issues such as:

- generating more rainfall,
- improving the energy efficiency of desalination processes,
- minimizing port pollution, and
- reducing water acidity.

EXPERIMENTAL DESIGN focuses on certain variables and how they impact one another. This is a type of applied research that helps businesses and other enterprises identify correlations, cause and effect, and resource requirements, as well as gain many other useful insights. This research is more specific and targeted.

There are multiple components to idea diffusion as well, including: (1) academic and scientific diffusion, (2) commercialization, and (3) the general public.

ACADEMIC AND SCIENTIFIC DIFFUSION occurs through mediums like peer-reviewed journals, academic papers, books, conferences, and demonstrations.

COMMERCIALIZATION refers to the process by which incubators and accelerators come in to assist fledgling entrepreneurs and research teams in building up the business case for their work (Figure 3). The process that entrepreneurs and "intrapreneurs" (new business developers inside large companies) pursue takes the innovation pipeline to its logical conclusion – the introduction of new products and services that can make a difference in people's lives.

Both the U.S. and Sweden have seen blue economy clusters naturally emerge around these types of programs, with government and academic research catalyzing basic scientific findings, and the private sector developing applications, products, and services on the back end. In other words, this process lends itself to: (1) cross-sector dialogue and communications, (2) differentiation of roles and responsibilities, and (3) potential for public-private partnerships (PPPs).

The **GENERAL PUBLIC** contributes to and circulates idea diffusion via specialty and mass media, social media, curriculum development and education, and documentaries.

PIPELINE SUPPORT refers to how these components are supported by a core set of functions that undergird all of them, as shown in Figure 4.

Catalysts Among Us

Sylvia Earle (pictured above) is an American marine biologist and former chief scientist at NOAA. She also founded Deep Ocean Exploration and Research (DOER) Marine, a deep-sea exploration engineering firm, and Mission Blue, a non-profit devoted to explore and protect the ocean. (Source: MarinersMuseum.org)

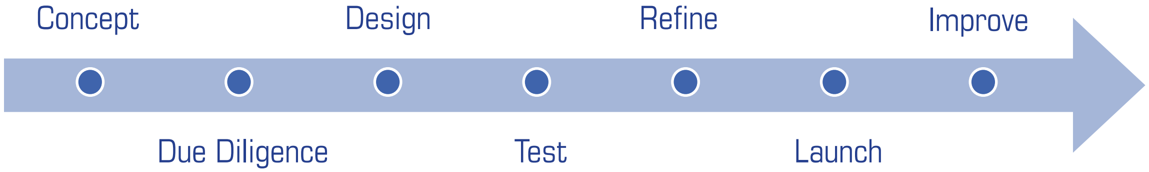


Figure 3. Commercialization, the final step of the Innovation Pipeline

Defining the Blue Economy: A Note on Methodology

Some authors use "blue economy" interchangeably with maritime industries. However, what the research team discovered is that while an increasing number of companies have adopted blue principles, different market segments cater to customers based on different value propositions. For example, companies like X Shore and Candela have positioned their electric boats as premium environmentally-sensitive products. Meanwhile, other boat manufacturers compete based on price and other metrics where the environmental footprint of their product is not a key differentiator.

Many traditional industries have also undertaken environmental initiatives to reduce carbon emissions and other forms of waste. For example, Carnival Cruise Lines is committed to reducing carbon emissions by 40% by 2030,[10] while Royal Caribbean and MSC Cruises have pledged to reduce emissions to net zero by 2050.[11,12] Cruising inherently generates waste, so while an argument could be made that they are not blue per se, their use of their commitment to the environment as a selling point demonstrates that they want to participate in the blue economy, thereby forming a potential customer base for blue researchers and innovators.

Many third-party data sources were consulted in the development of the report. For industry reports, there was often a lack of base years or projections, making the data very difficult to harmonize. They also organized information differently and varied in terms of what they included and left out. In many cases, there were competing data points for industry sizes, disaster costs, government budgets, etc. Therefore, all amounts are approximations.

Another issue arose in parsing out blue economy support dollars in the energy and carbon capture segments. Since energy solutions like wind, battery development, and others can be generated in a variety of ways, there is significant cross-over. To avoid the risk of double counting, we used the numbers for offshore wind research, hydrogen, and hydropower only.

All monetary amounts are in U.S. dollars and Swedish krona (SEK) unless otherwise noted. ●

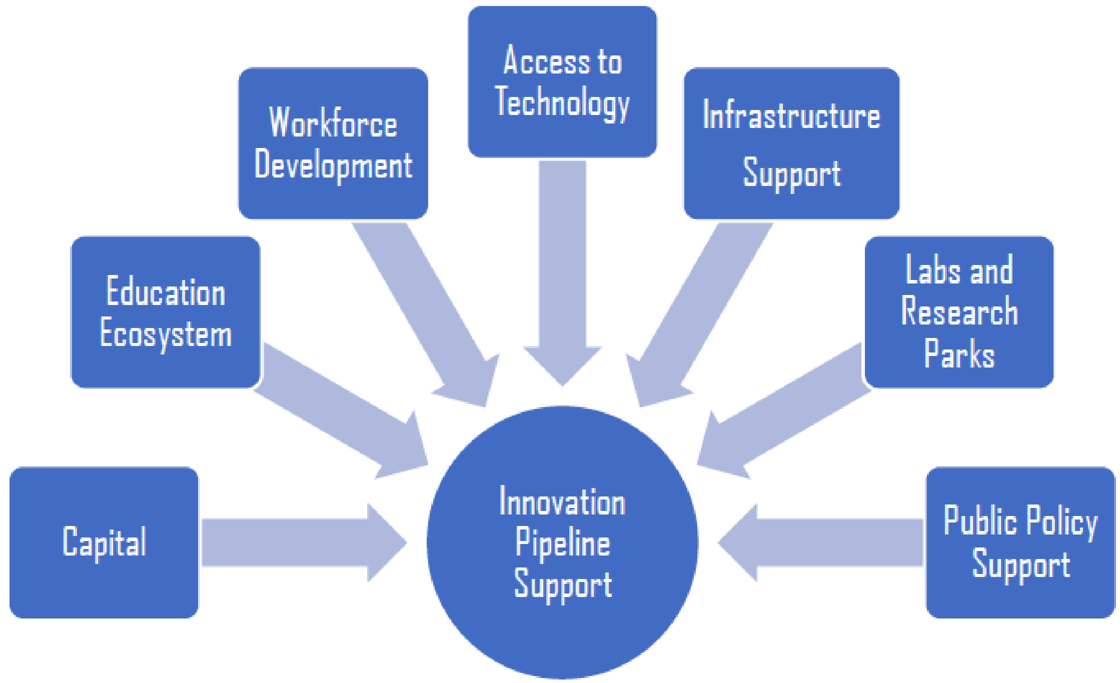


Figure 4. Core Functions Undergriding Innovation Pipeline Support

Royal Caribbean and MSC Cruises have pledged to reduce emissions to net zero by 2050. Cruising inherently generates waste, so while an argument could be made that they are not blue per se, their use of their commitment to the environment as a selling point demonstrates that they want to participate in the blue economy ...

The Need for Accelerated Environmental Research

The case for innovative blue approaches to water management from a risk management perspective is clear. The frequency of natural disasters worldwide has generally increased since as early as the 1970s.

According to the WMO and UN Office for Disaster Risk Reduction (UNDRR) "Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes," from 1970 to 2019, natural hazards accounted for 50% of all disasters, 45% of all reported deaths, and 74% of all reported economic losses.[13]

Global insurer AON conducted a study in 2022 and found that water-based disasters caused $231.62B in global economic losses in 2022, of which only $132B were insured.[14]

These figures only include extreme weather events such as floods, storms, and hurricanes. Costs associated with ocean acidification ($10B), ocean plastics pollution ($8B), and poor sanitation and hygiene ($260B) conservatively exceed $278B. These challenges have cascade effects that are reflected in the following:

***Pictured left,** The Ocean Reef Lab at Biosphere 2 at the University of Arizona is the largest isolated habitat research center on the planet. (Source: Unusual Places)*

- Rising insurance costs
- Elevations and housing costs due to rising seas and changes in flood zones
- Lost housing and plant, property, and equipment/ damages due to extreme storms
- Grey infrastructure repair, maintenance, and upgrades (e.g., seawalls, levees, dams, and water, sanitation, and hygiene)

Addressing the $509.62B in water-based natural disasters and other environmental impacts could therefore lead to significant economic risk reduction well beyond what is captured by these figures.

The rest of this chapter will examine several of these challenges and how research and innovation would help chart the path forward.

Ocean Acidification

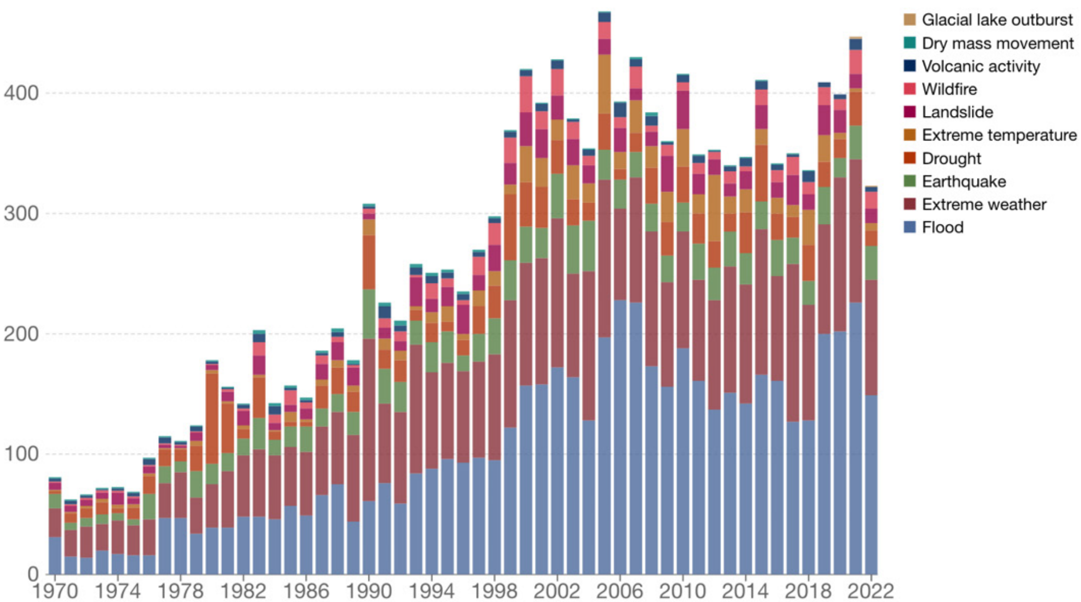
The oceans absorb around 30% of carbon dioxide (CO_2) released into the atmosphere through human activities (e.g., cars burning fossil fuels, deforestation changing land use).[15] This absorption of CO_2 by the ocean is known as ocean acidification (OA). In the past 200 years since the start of the industrial revolution, the pH of surface ocean waters has fallen by 0.1 pH units, representing around a 30% increase in acidity. Under business-as-usual, the pH of the ocean's surface could decrease to approximately 7.8 by 2100, a low pH level unseen since 14-17M years ago when the Earth was slightly warmer and undergoing a major extinction event.

OA also affects coral reefs – for areas like southeast Florida, where coral reefs generate $4.4B in annual sales, $2B in income, and 70,400 jobs, sensitive coral reef ecosystems and commercially important fisheries are at high risk.[16] Coastal reefs protect economic activity worth $319M per year in Florida, as well as $118M in Puerto Rico and $25M in the Virgin Islands. Globally, costs due to OA have been estimated at $10B annually.[17]

Columbia University's pioneering work on OA at the University of Arizona Biosphere 2 campus in the late 1990s helped established the basic science. Since then, several research and start-up projects have emerged to commercialize olivine and other alkaloids to reduce ocean acidity. Vesta,

Global reported natural disasters by type, 1970 to 2022

The annual reported number of natural disasters, categorized by type. This includes both weather and non-weather related disasters. (Source: Our World in Data)



public benefit company founded in 2019 and based in San Francisco, is working with coastal communities by spreading large amounts of ground olivine-containing rock onto coastlines where it can dissolve in seawater, thereby increasing the rate of CO_2 absorption by the ocean. The Ocean Foundation is also funding an International Ocean Acidification initiative. In partnership with the Global Ocean Acidification-Observing Network (GOA-ON), it is funding research in Puerto Rico, the Pacific Islands, and the Gulf of Guinea, and also established a regional training center with many public, private, and academic partners in Suva, Fiji.

Lilly1 Technology also presented their proprietary technology to enhance the olivine weathering process at the Climate Technology Showcase hosted by the Institute for Sustainable Development (ISD) and Swedish-American Chambers of Commerce of the USA, Inc. (SACC-USA) on November 4, 2022.

Biodiversity Stress

Species biodiversity in the oceans ranges from 0.7–1.0M species, excluding bacteria and other microbes and viruses. According to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) Global Assessment Report on Biodiversity and Ecosystem Services, one-third of fish stocks are over-fished and another 60% are being fished at their maximum sustainable levels.[18] Illegal, unreported, and unregulated fishing has also been shown to affect roughly 9.9–23.5M metric tons of fish catch valued at $23B in unlawful or undocumented revenue.[19] Land use, pollution, acidification, eutrophication, and rising ocean temperatures also contribute to stress on ocean biodiversity.

On March 4, 2023, the UN finalized a high seas biodiversity treaty that, among other things, will seek to conserve 30% of the ocean by 2030.[20] In the interim, significant research and entrepreneurial initiatives are already in motion, such as the following:

- The Consortium for Wildlife Bycatch Reduction was founded in 2004 to support collaborative research to understand interactions between threatened non-target species and fishing operations, enhance bycatch reduction approaches, and facilitate global information exchange.
- The Ocean Solutions Accelerator, founded by the Sustainable Ocean Alliance, has supported forty-five ocean-tech firms with $225M in lifetime funding. Some of the firms they are supporting that are working on bycatch reduction and ocean biodiversity include SmartCatch and SafetyNet Technologies.

Ocean Plastics and Water Pollution Management

Each year, 272.16M metric tons of plastic are produced, half of which are used to create single-use items like shopping bags and straws. 12.7M metric tons of this plastic ends up in the ocean, with plastic making up 80% of marine debris found from surface to deep-sea sediments.[21] As much as 80% of this plastic comes from land-based sources, such as urban and stormwater runoff, inadequate waste disposal, littering, and industrial and construction activities.[22] Meanwhile, ocean-based plastics originate primarily from the fishing industry, nautical activities, and aquaculture.[23] If business-as-usual regarding ocean plastics management persists, the annual volume of plastics entering the ocean will nearly triple from 9.9M metric tons in 2016 to 26.3M metric tons in 2040.[24] The annual cost of global ocean-based plastic consumer waste has been estimated at $8B.[25]

Only 15% of global plastic waste is actually recycled. As it is today, recycling is less economical than landfill or incineration, but over time, it has the potential to be $350-450 per metric ton more profitable because, unlike landfill and incineration, recycling generates revenue, or at least has the potential to break even. The global market for recycled plastics, valued at an estimated $59.8B in 2021, is estimated to reach $124.3B in 2030 with a compound annual growth rate (CAGR) of 9.58% from 2022 to 2030.[26]

Examples of innovation in this area and their focus areas include:

- **ecoSPEARS**, polychlorinated biphenyls (PCB) extraction and elimination
- **NSS WATER ENHANCEMENT TECHNOLOGY**, water ultra-purification
- **ZEPHYR DEBRIS REMOVAL**, skimming technology to remove trash and other pollutants
- **SWAY**, replacement of single-use plastics with packaging made from seaweed
    - Sway applies the principles of the circular economy to their products and entire supply chain.
    - Their seaweed-made plastics are fully compostable and offer an easy substitute for single-use plastics.

A 3-D-printed living seawall developed by Kind Designs. (Source: Kind Designs)

Rising Sea Levels

In 2021, global sea levels set a new record high of 9.65 centimeters above 1993 levels.[27] The rate of global sea level rise is accelerating and has more than doubled 0.15 centimeters per year throughout most of the twentieth century to 0.36 centimeters per year from 2006 to 2015 alone.

Rising sea levels cause higher background water levels, which lead to storm surges and more destructive hurricanes like Hurricane Sandy in 2012 and Hurricane Ian in 2022, both in the U.S. Higher sea levels also mean more frequent high-tide or "nuisance flooding." In the U.S., nuisance flooding along the coasts increased 300–900% from 1975 to 2015.[28]

In the U.S., coastal protection efforts to implement 80,467 kilometers of seawalls and other coastal barriers in twenty-two states could cost more than $400B over the next twenty years.[29] Florida would be the most impacted state, with statewide costs reaching nearly $76B by 2040 and costing more than $100,000 per person, followed by Louisiana and North Carolina. For nineteen other small and mostly unincorporated communities, seawall defenses by 2040 could cost more than $1M per person.

On the other hand, better understanding of "natural defenses" could yield significant dividends. The estuarine wetlands in the eastern and Gulf Coast regions of the U.S. are estimated to provide $8,235 per hectare per year in average annual storm protection value (measured in 2007 dollars).[30] Tidal marshes have also been shown to provide up to $9,565 per hectare per year in various ecosystem services. There are over thirty U.S. federal programs funding conservation, with some receiving federal oil and gas revenue, such as the Land and Water Conservation Fund (LWCF). In 2020, the Great American Outdoors Act fully and permanently funded the program with royalties from offshore oil and gas.[31]

A network of research and entrepreneurial actors have emerged to reinvent seawalls, bulkheads, and beach replenishment, including:

- **KIND DESIGNS**, winner of the inaugural Hummeltorp Evolution Award 2022 at the Climate Technology Showcase on November 4, 2022, for their use of 3-D printing technology to build eco-friendly "living seawalls"
  - 3-D-printed seawalls mimic coral reefs and mangroves, hosting a range of biodiversity and improving the quality of water.
  - Their seawalls have embedded water quality sensors and are made with recycled ocean plastic fibers.
- **SEAHIVE**, a University of Miami revetment research initiative

Underwater Noise Pollution

Underwater noise pollution impacts the ability of marine species to use sound to find prey, locate mates and offspring, avoid predators, guide navigation, locate habitat, hear and identify critical environmental cues for avoiding predators and finding food, and listen and communicate with other organisms.[32] Anthropogenic, or human-made, noise is a major source of unusual underwater noise pollution today.[33]

Commercial tankers are arguably the most ubiquitous source of high-intensity sound,[34] with around 58,000 merchants trading internationally.[35] The shipping industry has opportunities to capitalize on innovations in both vessel technology, design, and operations. The greatest potential for mitigating shipping noise is via ship-quieting technologies, which are cheaper to implement at the design stage versus retrofitting current vessels. For example, unconventional propeller designs for reducing noise pollution, such as skewed propellers, are comparable in costs to conventional propellers or can cost 10–20% more, depending on the type. Previous research has also demonstrated the potential of certain noise cancellation methods, such as Active Noise Control (ANC), on dampening noise generated by propellers.[36] The global marine propeller market, worth $3.6B in 2022, is expected to grow to $5.68B in 2029 and grow at a CAGR of 7.9% from 2023 to 2029.[37]

AdBm Technologies offers lightweight, flexible and modular design solutions suitable for high currents and large tidal changes. (Source: AdBm Technologies)

Examples of innovators for abating underwater noise pollution and their focus areas include:

- **ADBM TECHNOLOGIES** - Founded by three University of Texas at Austin scientists in 2012, AdBm Technologies is an acoustical engineering company based in Austin, Texas, specializing in noise abatement technology for marine environments.
- **MEGASORBER** - Acoustics absorption, noise barrier, and vibration damping materials
- **OCEAN ACOUSTICS RESEARCH** - Scripps Institution of Oceanography

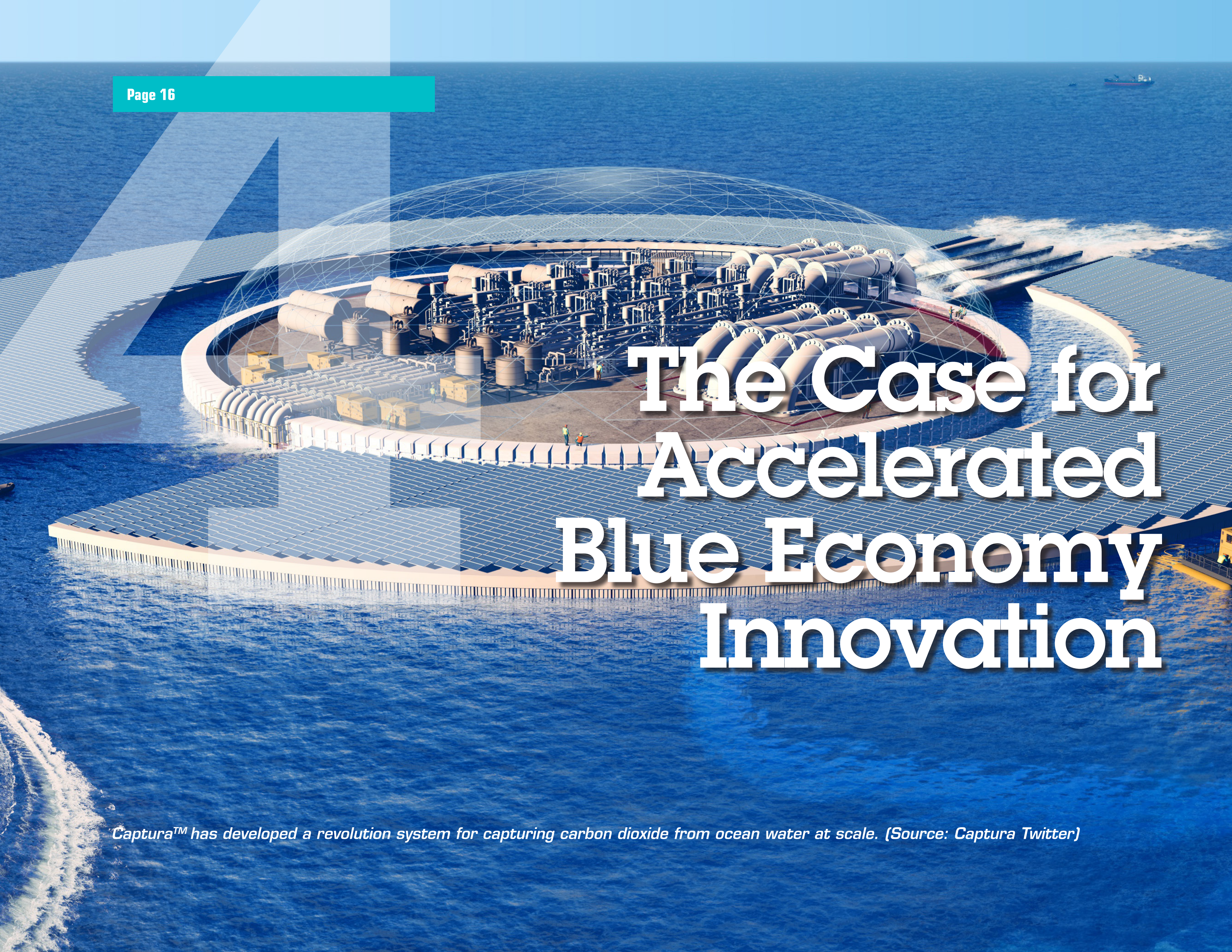
Aging Water, Sanitation, and Hygiene (WASH) Infrastructure

Although the proportion of people with access to clean drinking water grew by 74% from 2015 to 2020, over 700M people around the world still do not have access to clean drinking water. This is compounded by aging infrastructure in many developed countries. The American Society of Civil Engineers gives the U.S. water infrastructure a C-, citing the fact that there is a water main break every two minutes, and an estimated 22.7M liters of treated water are lost each day.[38] The World Health Organization estimates that economic costs due to poor sanitation services worldwide could be as high as $260B per year.[39]

Research and innovation is being carried out across a range of ideas, including:

- **AQUA ROBUR TECHNOLOGIES AB** - smart water sensor and Internet of Things (IoT) technology
- **LOGISTEC AND SANEXEN ENVIRONMENTAL SERVICES INC.** - seismic resilient pipes
- **COLFERROX** - treating contaminants with small dosages of colloidal particles
- **PUROLITE** - resin-based purification and extraction. Founded in the 1980s, Purolite develops and manufactures resin beads applicable for various industries to remove, recover, or separate specific elements and compounds. Purolite has five R&D centers, nine application labs, and four production facilities. Their products offer a more budget-friendly and time-saving option than their competitors, and their resin treatment systems are better for the environment. ●

4 The Case for Accelerated Blue Economy Innovation



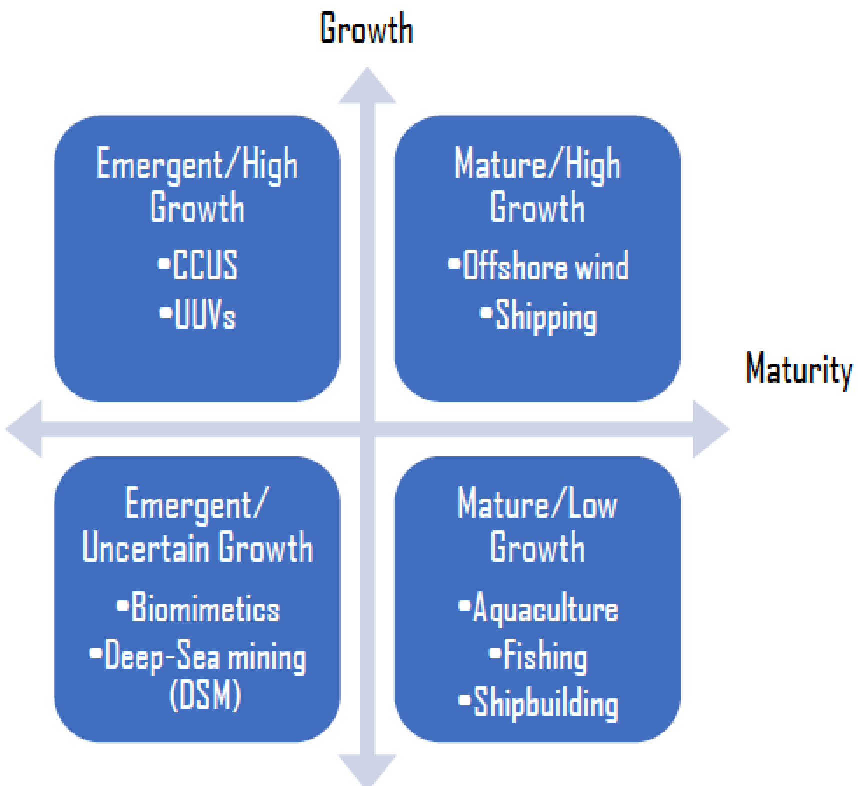
Captura™ has developed a revolution system for capturing carbon dioxide from ocean water at scale. (Source: Captura Twitter)

From a research and innovation perspective, there are many opportunity targets for blue-ing water-based industries.

There are large market, low-growth industries like fishing, aquaculture, and shipbuilding that might be ripe for reinvention.

There are also large market, high-growth industries that could favorably differentiate themselves by embracing sustainability-conscious practices, like tourism (particularly cruising) and offshore drilling. Rapidly-growing industries like desalination and offshore wind energy also need to continue to innovate and realize their full potential.

Finally, there are emerging industries like biomimetics, robotics, unmanned underwater vehicles (UUVs), and carbon capture, utilization, and storage (CCUS), where in many cases, the true market potential could be orders of magnitude higher. The following is a brief snapshot of some of these industry opportunities.



Opportunities for Blue-ing Water-Based Industries Organized by Growth vs. Maturity

Aquaculture

In 2020, the global aquaculture market was valued at $204B. This market is expected to grow to $262B by 2026 with a CAGR of 5.13% from 2021 to 2026.[40] Longer term, seafood protein consumption will grow from 7% in 2018 to 9% in 2050.

Aquaculture is expected to double in production and represent an increasing proportion of global marine harvest by 2050, approaching levels of wild catch production and helping to close the supply demand gap for seafood created by stagnant fisheries.

Seaweed is another growing sector and business opportunity that cuts across aquaculture, biotechnology, and pharmaceuticals, given its low fixed costs and input requirements.[41] For example, the market for carrageenan, a chemical compound made from red seaweed, was estimated to be worth $600-700M in 2019 and is projected to reach $1B by 2024.[42]

Several examples of innovators in aquaculture include:

- **FLIPFARM,** with their innovative and efficient semi-automated oyster-growing system, which dramatically reduces the human effort required for farming
- **AQUABYTE**, a technology company founded in 2017 that uses an AI-based software platform to monitor aquaculture farms for real-time metrics such as levels of sea lice, appetite detection, and biomass estimation
- **NEXT TUNA**, which is co-funded by the European Union (EU) and will be the first company to plan and build a land-based Recirculating Aquaculture System for Atlantic Bluefin Tuna
    - This will help to provide a sustainable source of Atlantic Bluefin Tuna to meet the world's growing demand.
    - Next Tuna's solution will help relieve wild tuna of their endangered species status.
    - They directly support SDGs 12 (Responsible Consumption and Production) and 14 (Life Below Water).

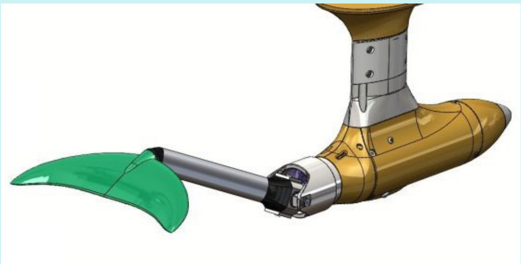
Biomimetics

Biomimetics refers to the emulation of natural systems and elements through the fields of engineering, chemistry, and biology for the purpose of solving complex human problems. In other words, biomimetics is the "transfer of ideas and analogues from biology to technology" or "biologically inspired design."[43] Based on the key idea that nature always functions on the principle of economy and optimal efficiency, the biomimetics industry has the potential to yield substantial monetary benefits, increase access to natural resources, and drive appreciation of non-monetary values, sustainability, conservation, and stewardship.

In 2022, the global biomimetics market was estimated to be worth $26.32B and is projected to reach $83.84B by 2030 with a CAGR of 18.00% between 2023 and 2030.[44]

Biomimetic approaches to industry reinvention include:

- **MITIGATING BIOFOULING**, which is when marine organisms adhere themselves to solid surfaces like submarine hulls and nuclear power plant pipes.[45] One example of the economic losses associated with marine biofouling is biofouled ships, which experience increased friction and weight, thereby consuming more fuel. Biofouled ships also risk the transfer of invasive species across oceans.
- **THE GLOBAL MARKET FOR MARINE COATINGS** is also predicted to reach $15B by 2024.
- **MEDICAL BIOMIMETICS**, which is driven by factors such as increasing demand for organ transplants and prosthesis, as well as the fields of tissue engineering and nanomedicine.[46]

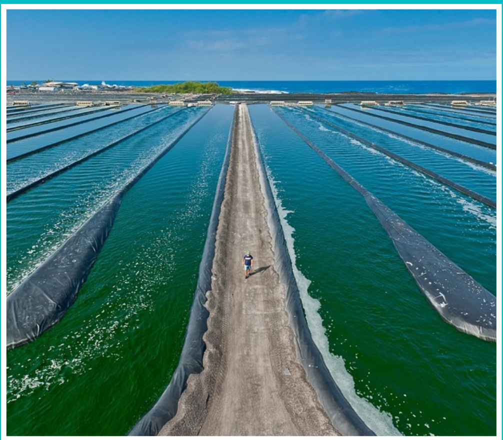


Dolprop's "DolPOD" technology. (Source: Dolprop Industries AB)

Global companies like Ford, GE, Herman Miller, HP, IBM, and Nike have begun collaborating with scientists and designing labs to explore innovative technology.[47] One Swedish company known as **DOLPROP INDUSTRIES AB** is currently developing an environmentally-friendly and low-noise electric marine propulsion system. Their technology uses a biomimetic approach that generates thrust via a "thunniform swimming" sine-wave motion often seen in dolphins, whales, and fast fish species like tunas and barracudas.[48] Their goals are to increase

Additional Applications for Blue Biotechnology

- Extraction of enzymes for the paper, textile, and detergent industries, as well as laboratory applications
- Cosmetics, including the extraction of bioactive properties from marine life (such as algae), which provides new active ingredients with antioxidant, moisturizing, anti-inflammatory, and photo-protective properties that could be added to creams and lotions
- Food, including food supplements and nutraceutical additives



Cyanotech's spirulina process culture ponds. (Source: Cyanotech ©Marcus Rohrer)

energy efficiency, abate noise levels, and reduce injury on marine life and search and rescue victims, compared to traditional propellers.

Biotechnology and Biochemistry

In 2021, the global market for marine biotechnology was valued at $4.39B. This market is expected to be worth $5.645B in 2027 with a CAGR of 5.16% between 2022 and 2027.[49] In Europe alone, the marine biotechnology market has been predicted to reach $1.3B by 2024 (using 2020 as a baseline), with the pharmaceutical and food sectors accounting for over 60% of added value.[50] In 2020, the turnover of pharmaceutical products of marine origin in Europe was almost $400M, with the highest market share value in the blue biotechnology sector. In terms of revenue generated, the food sector followed with $290M.

Microalgae can function as an important source for biofuels. According to ExxonMobil, five times as much biofuel per acre could potentially be obtained from algae than from sugar cane or corn, making algae-based biofuel a more productive venture.[51] Furthermore, the electricity produced from biofuel obtained from microalgae can be cost-competitive with solar energy and biomass-generated electricity, meaning it could attract quite a large market if brought to the grid.[52]

Biochemical and molecular characterization has been considered the most widely used biotechnology. Emerging technologies in basic research include omics technology, pharmacological analysis, and bioinformatics. Technology that optimizes the conditions of cultivation, harvesting, and extraction are central to most business models with immediate commercial exploitation, especially for food and nutraceutical applications. Recent blue biotechnology efforts aim at utilizing aquaculture to farm and harvest resources rather than exploit the ocean's natural resources.

There has also been growing commercial interest in marine genetic resources, with the rate of patent applications related to marine genetic material exceeding 12% per year.[53] For example, a sea sponge originating from the Caribbean facilitated the development of anti-leukemia and human immunodeficiency virus (HIV) drugs in the 1960s and 1980s, respectively. In the U.S., potential benefits from pharmaceutical bioprospecting in Jamaica have been estimated at $70M, but with the odds of successful new drug development being relatively low, the benefits are unlikely to be observable for a long time.

Pharmaceutical companies tend to be some of the biggest players and revenue-earners in the field of marine biotechnology. **CYANOTECH CORPORATION**, for example, brought in a total of $32.3M in revenue in 2021.[54] **AQUAPHARM**, a marine biotech company from Scotland, raised $5.8M in financing from a funding round held with only their existing investors.[55]

Carbon Capture, Utilization, and Storage

In 2020, the global market for CCUS was valued at $1.9B. This market is expected to be worth $7.0B in 2030 and grow at a CAGR of 15.59% from 2021 to 2030.[56]

CCUS could be a key method for achieving clean energy transitions, but utilization of CCUS technologies have been slow to take off. These technologies are still early in development and therefore more expensive to develop. They also face high associated costs and an inability to compete with other alternative energy sources like wind and solar.[57]

Transport and storage costs vary greatly, with onshore pipeline transport ranging from $1.82–12.74 per metric ton of CO2 in the U.S. Onshore storage shows an even greater spread, but still, more than half of onshore storage capacity is estimated to be available below $9.1 per metric ton of CO2. Storage costs can even be negative if the CO2 is injected into and permanently stored in oil fields, which enhances production and generates more revenue from oil sales.

CCUS costs have been falling over time, and this trend should continue as the market grows, technology develops, finance costs fall, economies of scale are reached, and more experience is gained in the industry overall. For example, the cost of CO2 capture in the power sector has dropped 35% between the development of the first and second large-scale CCUS facilities from $100.10 to $59.15 (respectively) per metric ton, with average costs for similar future projects expected to be even lower by 2027 ($37.15) per metric ton.

The International Maritime Organization (IMO) has also invested in partnerships for marine decarbonization in less-developed countries (LDCs) and small island developing states (SIDS).[58] Further examples of policy instruments for CCUS development and deployment that serve to support funding include: grant support and capital funding for targeted projects, such as the United Kingdom (UK) CCUS infrastructure fund and the EU Innovation Fund; operational subsidies, like the Netherland's Sustainable Energy Transition subsidy scheme; and carbon pricing, like Norway's carbon tax on offshore oil and gas:[59]

Examples of innovative CCUS technologies and approaches include:

- **HEIMDAL**, a start-up pioneering "ocean-assisted" carbon removal that can remove CO2 at the price of $430.92 per metric ton
- **EBB CARBON**, with their use of electrochemistry to enhance the ocean's ability to capture carbon from the air
- **CAPTURA™**, which was founded in 2021 and stems from technology developed in Caltech's laboratories.
    - Captura™ proposes a low-cost decarbonization solution that relies on the ocean and would only minimally impact the ocean environment.
    - Their ultimate vision is a facility that treats shallow water to remove its CO2 content, and then returns the water to the ocean. The decarbonized water will then sit on the top of the ocean and interact with the atmosphere to draw an equivalent amount of CO2.

Desalination

In 2019, the global desalination market was valued at $13.8B. This market is expected to grow to $29.1B by 2030 and at a CAGR of 7.75% between 2020 and 2030.[60]

Historically, desalination plants for industrial use have been cost-prohibitive and environmentally harmful. A major concern of the desalination industry is high energy consumption levels for leading technologies. It has been estimated that 15,000 kilowatt-hour (kWh) of power is used to generate each 3.79M liters of freshwater.[61]

The reverse osmosis membrane tubes and electric water pressure pumps at Saudi Arabia's SAWACO Desalination Plant in Jeddah. (Source: New York Times)

The energy used to power desalination systems typically comes from fossil fuels.[62]

However, technology has been growing that helps reduce desalination plant construction costs and the total cost of water.

Renewable energy-powered plants are starting to become commercially available, scalable, and affordable for companies other than large-scale municipalities. For example, **TEL AVIV-BASED TETHYS SOLAR DESALINATION**'s solar-powered, zero greenhouse gas emitting desalination plant uses recycled materials and can supply up to 9463.5 cubic meters of water daily for a tenth of the energy costs for a traditional power plant.

Another industry concern is brine discharge. It has been shown that producing 95M cubic meters of freshwater also means producing 141.5M cubic meters of brine.[63]

However, herein lies an opportunity to develop a whole new industry around "mining" the numerous elements contained in seawater.[64]

For example, the EU has funded efforts to recover elements like magnesium, lithium, and rubidium from seawater. In the Middle East, the **SANDOOQ AL WATAN** initiative and the **KING ABDULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY** (KAUST) have issued competitions for innovative brine discharge projects.

On a more local scale, coastal communities are also increasingly turning to the sea to meet their drinking water needs, but inland communities are also impacted by the tendency of groundwater to become more brackish over time.[65]

Water managers are increasingly looking at desalination as a technical, supply-side solution for meeting water demands and remediating the negative effects of climate change on water resources. These needs have prompted a 57% increase in the capacity of desalination plants on-line from 2012-2017.

SIDS and developing nations present another business opportunity for the desalination industry as more of those populations turn towards the seas for clean water resources. By 2050, the market for desalination is forecasted to triple in size because of stress on the world's freshwater resources and groundwater sources.[66]

Saudi Arabia, for example, has doubled their desalination capacity within the last decade from 1.1B cubic meters in 2010 to 2.2B cubic meters in 2021.[67]

Some predict that technological advances will increase the viability of desalination by decreasing the costs of freshwater production by up to 60% by 2030.[68]

Fishing

The global fishing market was valued at $228.3B in 2021 and is projected to grow to $266.3B by 2028 and at a CAGR of 2.6% from 2022 to 2028.[69]

On an international scale, hundreds of millions of dollars have been invested in preserving marine resources and supporting the role of coastal fisheries in society and the economy via the UN Food and Agriculture Organization (FAO) Coastal Fisheries Initiative (CFI). With a total program cost of $235M, the Global Environmental Facility (GEF) Trust Fund (TF) has provided $33M.[70] Co-financiers provided $201M in grants and in-kind. These co-financiers include other GEF agencies like the UN and World Bank, national governments, the Walton Family Foundation, academia, and other non-governmental organizations (NGOs) and civil society organizations (CSOs).

Provincetown fisherman Eric Rego (left), Marine Fisheries Research Program Director Owen Nichola (center), and biologist Dave Chosid onboard a sea scallop fishing vessal for a research trip. (Source: Beau Gribbin, Marine Fisheries Research Program)

Seafood protein consumption will grow from 7% in 2018 to 9% in 2050.[71]

Others project that the global demand for fish will double from 2015 to 2050, due to both global population growth and the increasing affluence of the world's populations.[72]

However, even the current level of global fishing capacity is estimated to be 200% higher than what is sustainable.[73]

Thus, bluer fishing solutions are necessary to prevent severe and irreparable overfishing while still meeting the global demand for seafood.

The Center for Coastal Studies' **MARINE FISHERIES RESEARCH PROGRAM** in Provincetown, Massachusetts, presents one example of reinvention and innovation in the fishing industry. The goal of the program is to create connections and understanding between fishermen and scientists for the purpose of accelerating research. This cooperation combines the skills and knowledge of fishermen with the tools and techniques supplied by scientists.

The program conducts research with the purpose of addressing scientific and policy-related issues faced by Cape Cod fishermen and shellfish growers.

Marine Tourism

In 2019, the global market for marine tourism was valued at $602.8B. By 2030, this market is expected to grow to $1.21T with a CAGR of 7.2% from 2020 to 2030.[74]

When it comes to marine tourism, the cruise

The Letty Expedition Yacht is one of Ecoventura's first-class vessels for their Galápagos cruises. (Source: Ecoventura)

industry is a major concern for the ocean environment, but it has potential to improve and benefit from turning blue. During the COVID-19 pandemic, when there was a pause in the global cruise industry, significant beneficial environmental effects were observed – agricultural-related environmental pressure declined by 2% and energy emissions decreased by 7%.[75]

During the height of the pandemic, many cruise lines retired their ships early as opposed to continuing to finance them.[76]

Thus, this industry is currently experiencing an increase in ship production, posing immense potential to build and design more sustainable vessels that can save energy and reduce emissions. Eco-friendly ships can attract tourists that are seeking more sustainable travel and vacation options. In 2022, Booking.com published a report in which 81% of surveyed travelers confirmed that sustainable travel was "important to them," and 40% of travelers declared that they actively search for sustainability information when booking trips.[77] In the U.S., marine tourism and recreation accounted for 71.2% (2.5M workers) of total employment and 42.9% ($150.7B) of total GDP in its marine economy.[78]

Most of this employment and GDP was contributed by "Eating and Drinking Places" (76% and 59% respectively), followed by "Hotels and Lodging Places" (18% and 33%) and "Amusement and Recreation Services" (3% for both).

One example innovator in the marine tourism sector is Ecoventura, the first Galápagos cruise line to offset carbon emissions from their expedition yachts. Their latest vessel, MV Origin, features a water treatment system, ecological toilets, and even reusable plastic water bottles.

Offshore Renewable Energy

The global offshore wind energy market was valued at $47.5B in 2022. This market is expected to reach $266.9B in 2032 and grow at a CAGR of 21.14% from 2023 to 2032.[79]

By 2050, it is predicted that the share in demand for offshore renewable energy in comparison to offshore non-renewable energy will rise from its current share of 26% to 82% by 2050.[80]

Specifically, the offshore wind market, will grow to account for 50% of the ocean's capital expenditure, or "capex," by then. This will occur simultaneously with the decline of the oil and gas industry, which is predicted to fall from 80% of the ocean's capex to a mere 25% by 2050.

The construction of wind turbines has high upfront costs usually ranging between $2-4M per turbine.[81] However, these investments tend to recuperate that value within the first five years, or even in the first three if they are in a prime location, like offshore where wind speeds are higher.[82]

Furthermore, many federal governments are providing and initiating incentives for investment in the wind energy market, such as federal energy subsidies, loans, and tax credits in the U.S.[83]

Currently, the U.S. Department of Energy's (DOE) Wind Energy Technologies Office (WETO) is allocating over $300M to offshore wind research, development, and demonstration projects that are selected through competitions.[84] WETO is also financially supporting a national offshore wind R&D consortium with $41M. This is a part of WETO's commitment to overcoming barriers to offshore wind development, such as challenges due to project installation, grid interconnection, high costs of energy, and the mitigation of environmental impacts.

Meanwhile, the global offshore hydropower market was valued at $2B in 2017, and is projected to grow to $3.7B by 2030 and at a CAGR of 5.26%

Oscilla Power Technologies. (Source: Oscilla Power) from 2018 to 2030.[85] Offshore hydropower conducted in oceans is a relatively emerging endeavor which uses tidal currents or the power of waves to generate energy.[86] The U.S. has the world's second largest installed capacity of hydropower at about 100 gigawatts (GW), and this sector currently employs approximately 300,000 workers.[87] It has been estimated that the U.S. could add 60,000 megawatts (MW) worth of capacity by 2025.

This number could be drastically increased when considering offshore wave power, which has an estimated capacity of 90GW. With current technological capabilities, only 14GW of this could be realizable by 2025. All in all, the expansion of the U.S. hydropower market alone could create a cumulative 1.4M jobs by 2025.

OSCILLA POWER is one example of a company working on innovations in wave energy. Founded in 2009 and located in Seattle, Washington, they are currently developing their Triton wave energy convertor, which will have a rated power of 1 MW. These Triton converters can be arrayed together to form utility-scale power plants. The harnessed power can also be used to develop the self-charging capability of autonomous underwater vehicles (AUVs) and extend the range of their missions.

Ocean Exploration and Submersibles

The global underwater drone market was valued at $3.24B in 2021. By 2027, this market is expected to reach $6.77B and grow at a CAGR of 15.88% from 2022 to 2027.[88] Likewise, the global market for UUVs was valued at $2.54B in 2022 and is expected to reach $8.46B by 2030 with a CAGR of 18.75% from 2023 to 2030.[89]

The global navigation and survey instruments market more than doubled between 2001 and 2011, being worth $7.5B in 2001 and then $16B in 2011.[90]

The demand for ocean data technology in the U.S. is largely driven by the demand of the U.S. DOD.[91]

Marine robots like AUVs and UUVs can be used for defensive purposes in order to keep surveillance on borders and monitor international naval movement.[92]
Moreover, oil and gas companies utilize marine observation equipment to complete pre-installation surveys and baseline surveys before construction, drilling, production, and decommissioning to ensure safe operations.[93]

Generally, AUVs and UUVs rely on a battery or other internal power source that limits the vehicle's range and duration, as it needs to be charged periodically.[94]

Opportunities exist to develop underwater docking and charging stations that could reduce the vehicle's reliance on support crew, increase mission duration, lower carbon emissions, and allow the vehicle to offload and save data underwater. These docking stations are still in demo periods and are not commercial yet, however, investments in this industry can make this a reality. Beyond defense and resource extraction, ocean data technology is produced and consumed by research communities studying the ocean environment and how it interacts with man-made systems.[95]

TalTech's underwater robot. (Source: Hendrick)

Further investment in this industry can significantly expand the innovations available in collecting ocean data, and therefore improve the study of climate change. New data and tools can help researchers understand ocean health, measure sea-level rise, track the impacts on the fishing industry, predict weather variation, optimize offshore wind energy generation, and understand the impacts of other ocean-based technologies.[96]

Examples of innovators in the ocean exploration and submersibles industries include:

- **ANDURIL**, a military technology company creating AUVs for deep-water survey, inspection, intelligence, surveillance, and reconnaissance operations
- **TERRADEPTH**, a start-up using unmanned submersibles to create a holistic picture of the subsea environment through data collection and visualization
- **THE TALLINN UNIVERSITY OF TECHNOLOGY** in Estonia, home to one of Europe's top fifteen underwater robotics research teams.
    - They are developing autonomous robots which can navigate deep seas and collect data while exploring territories no human can physically reach.

Candela's C8 all-electric recreation boat, released in 2021.

(Source: Paul Wyeth, MBY)

Shipbuilding

The global market for shipbuilding was valued at $142.52B in 2020[97] and is expected to reach $195.48B by 2030 with a CAGR of 3.57% from 2021 to 2030.[98]

Some companies and organizations have been experimenting with using composite materials (as opposed to steel) to construct new ships. Composite materials never rust and are typically much more durable than steel, meaning ships will have extended lifetimes and need less repairs.[99] Even at the end of these ships' lives, they will have a higher probability of being repurposed – 75% of composite ships are repurposed, in comparison to only 34% of steel ships.

Furthermore, ships made with composite materials can provide a decrease in their weight by 30%, therefore consuming approximately 10% to 15% less fuel and ultimately leading to a reduction in greenhouse gas emissions.[100]

THE REALIZATION AND DEMONSTRATION OF ADVANCED MATERIAL SOLUTIONS FOR SUSTAINABLE AND EFFICIENT SHIPS (RAMSSES) project sponsored by the EU developed a prototype ship hull made of composite materials and discovered that it weighed 24% less. They estimated that a ship equipped with this hull would reduce its environmental footprint by 25%.[101]

The Swedish company **CANDELA** offers another example of innovation in the shipbuilding industry with their electrified boats:

- Candela works on electrifying marine transportation by making electric boats that perform better than their fossil fuel competitors.
- The Candela C8 is a long-range electric cruiser that flies above the waves in silence and consumes a fraction of the energy that traditional boats use.

Marine Mining

The global market for deep-sea mining (DSM) was estimated to be worth $650M in 2020. This market is projected to grow to $15.3B by 2030 with a CAGR of 42.04% from 2021 to 2030.[102]

The marine mining industry is comprised of two sectors: seabed mining and DSM. Seabed mining consists of the extraction of underwater minerals and deposits from the sea floor at a depth of less than 200 meters. DSM, on the other hand, is an emerging and experimental industry consisting of mineral deposit extraction that occurs at a depth of 200 meters and greater, usually around the continental shelf and within area under the high seas. The International Seabed Authority has already issued twenty-nine contracts that authorize the exploration of mineral deposits covering an area larger than 1.3M square kilometers.[103]

Some argue that an expansion of this industry is beneficial because many of the rare earth minerals that can be collected through DSM are necessary for the technology powering renewable energy sources like solar, wind, and hydropower.[104] Furthermore, DSM companies argue that this type of mining will have lower environmental and social impacts than land-based mining. One report published by a Canadian deep-sea mining company found that carbon emissions were 70% lower for DSM in comparison to terrestrial mining.[105]

Reports by the World Bank, the Deep Sea Mining Company, and MiningWatch Canada all examined potential risks of DSM and urged communities in the Pacific to use a high degree of caution when engaging in mining ventures, as they can likely bring irreparable damage to the underwater ecosystems, fisheries, biodiversity, and social and

Impossible Metal conducts environmentally responsible harvesting with a hovering robot designed not to dramatically disturb the seabed as it mines. (Source: Impossible Metals)

economic construction of these communities.[106, 107] Scientists continue to warn that DSM will cause a permanent loss of biodiversity, but the exact extent remains unknown, as many of these ecosystems have not been well-studied.[108]

Research is been conducted regarding how to make DSM bluer. One report conducted by the Blue Mining Consortium found that the most important way to make DSM more environmentally-friendly would be to reduce the environmental plume that occurs when mining.[109] However, this report still considers this to be a great technological challenge, alongside the need to improve the reliability of machines on the seafloor in the first place.

Several examples of companies seeking to reinvent the marine mining industry include:

- **MOANA MINERALS**, with their Cook Islands Nodule Project for exploring the challenge of sourcing metals from seafloor nodules of the Cook Islands
- **IMPOSSIBLE METALS**, a start-up that looks to conduct environmentally responsible selective harvesting on the ocean seabed by using technology that delicately extracts minerals with a hovering robot. Impossible Metals distinguishes themselves from other DSM companies that use dredging designs that destroy underwater habitats.

Manufacturing

The global market for marine electronic equipment was valued at $5.04B in 2022. By 2030, this market is projected to reach $7.18B with a CAGR of 5.19% between 2023 and 2030.[110]

One way that ship equipment can be made more blue is through the production and distribution of liquid natural gas (LNG) fuel capable engines. As shipping companies turn towards reducing emissions, the alternative fuels market has gained traction. Trends have pointed towards increased demand for engines with methanol, hydrogen, and ammonia options. In 2022, 44% of the orderbook for ship equipment, as reported by the World Fleet Register, was made up of alternate-fuel capable equipment.[111] In 2017, this number was only 14%.

LNG engines can have significant effects on ship emissions. LNG engines have been found to reduce CO_2 emissions by about 20–25% in comparison to diesel engines. Moreover, LNG engines decrease nitrogen oxide emissions by almost 92%, and they can almost completely eliminate sulfur oxides and particulates emissions.[112]

Data from the World Fleet Register has demonstrated that more than 5,000 vessels in 2022 had significant energy saving technologies (ESTs) onboard, when in 2018, only 3,000 vessels had EST equipment.[113] Some of the most popular

MAN Energy Solutions. (Source: MAN Energy Solutions)

ESTs equipped by ships in 2022 included exhaust gas economizers, propeller ducts, and rudder bulbs.[114] Exhaust gas economizers can save a ship about 4–6% of fuel, while propeller ducts can save 3–8%. In the long run, these fuel savings turn into money saved for both ship owners and ship companies, as well as overall reduced emissions.

One company on the frontlines of innovation in manufacturing is **WÄRTSILÄ CORPORATION**, which designs and sells ESTs for vessels. One such EST Is their propeller-rudder system, Energopac, which reduces fuel consumption and emissions and lowers vibration levels onboard.

Another company is **MAN ENERGY SOLUTIONS**, which offers cost-effective hybrid propulsion systems that combine battery power and combustion engines. This fuel flexibility ensures that ships will meet strict emissions regulations. With their multi-fuel engines, they have created solutions to several of the challenges posed by LNG engines, such as ensuring constant engine availability for the ship.

Transportation

In 2020, the global shipping container industry was valued at $6.41B. This market is expected to grow to $14.20B by 2028 and at a CAGR of 12.00% from 2021 to 2028.[115]

Beyond adding blue capacity to transportation vessels, sustainable port infrastructure can also be supported by greater investments. For example, shore-side energy (SSE) allows ships to plug into an onshore power source and then shut down their engines when at port. SSE has the potential to reduce pollutants released by ships by 90% and greenhouse gasses emitted by 50% when in port waters.[116] The EU is currently offering subsidies of 20–50% for private operators who install SSE and have it operational by 2025.

Ships and maritime activity in general are also some of the main factors responsible for the majority of accidental translocations of invasive species.[117] When ships leave a port, they fill their ballast tanks with water for balance, and then at the next port, they empty out the water and may relocate non-native species unknowingly. Annually, the damage caused by invasive species globally is estimated to cost $1.4T, or about 5% of the global GDP.[118] With funding, more actions can be taken to mitigate this issue, such as: researching the probabilities of non-indigenous species appearance, analyzing risk based on volumes and origins, inspecting port policies, monitoring routine species at ports, and implementing management plans.[119]

In Europe, the **EUROPEAN ONSHORE POWER SUPPLY ASSOCIATION** (EOPSA) is one example of an association working to transform ship stopovers with SSE by connecting key players to promote innovation, speed up installations, and advocate for global solutions.

The PosHYdon pilot project is located at the offshore oil and gas platform off the coast of the Netherlands.

(Source: PosHYdon)

Offshore Natural Resources

The global market for offshore drilling was valued at $31.26B in 2018. By 2026, this market could reach $56.97B and grow at a CAGR of 8.95% between 2019 and 2026.[120, 121]

The offshore oil and gas industry is often seen as counteractive to the goals of the blue economy, as they contribute heavily to fossil fuel emissions and climate change in general. However, this is also an industry where individual investors could benefit significantly by going blue.

Drilling projects are at risk of "stranded assets" in the case of oil projects closing early due to governmental policies and unprofitability. The study noted that $1.4T worth of assets globally are at risk of being stranded if international governments fulfill their emissions reduction pledges and fossil fuel demand consequently falls. $362B of this could be attributed to U.S. investors.[122]

An opportunity exists for offshore oil and gas companies to turn blue by seeking to create hydrogen power within their operations and existing infrastructure. While cost still remains a hurdle in switching stations from natural gas to hydrogen, the technology switch would not be as difficult. By 2030, this has the potential to create 700,000 jobs in the U.S. and bring in $140B in revenue annually.[123]

One example of an innovative project in the offshore natural resources industry is **POSHYDON**, a pilot project off the coast of the Netherlands where green hydrogen will be produced offshore on a fully-electrified operational oil platform for the first time.

- To power itself, PosHYdon will integrate three energy systems in the North Sea: offshore wind, offshore gas, and offshore hydrogen.
- To make green hydrogen, seawater is converted to demineralized water, and then the demineralized water is converted into hydrogen using electrolysis.
- This pilot project is intended to inform scientists and engineers about how offshore conditions affect this process, so that they can successfully develop large-scale, green hydrogen production systems in the future.
- The project received a $4.2M subsidy from the Dutch government in 2021 to advance the project. ●

The Blue Economy Ecosystem in the United States

The U.S. is a global leader in innovation and has developed a robust national innovation system over many years. However, leaders like Robert Atkinson, president of the Information Technology & Innovation Foundation (ITIF), argue that it is "in crisis." Regarding support for blue innovation, this is certainly true. Findings from the previous two chapters reveal that water-based environmental challenges and economic opportunities affect the U.S. bottom line by $490.7B at a minimum,[124, 125] but current U.S. R&D funding levels of $3.9B are only 0.8% of this total. Increasing R&D levels to 2.5% would require approximately $8B in funding increases. Raising it to leadership levels of 3.5% would require more than a four-times increase to reach $17.2B in R&D and innovation support.

U.S. coastal counties are home to 40% of the country's population.[126] This migration to the coast is one of the reasons that storms, floods, and droughts cost the U.S. $144.9B in 2022. According to the U.S. Bureau of Economic Statistics, the marine economy accounted for 1.7%, or $361.4B, of current-dollar U.S. GDP in 2020.[127] The COVID-19 pandemic hit the marine economy particularly hard. Real (inflation-adjusted) GDP for the marine economy decreased 5.8% from 2019 to 2020, compared with a 3.4% decrease for the overall U.S. economy. Due to market expansion in 2021 and 2022 in the rebound from the pandemic, it is safe to say that $490.7B understates the total economic impact of water-based environmental challenges and economic opportunities.

Indeed, NOAA projects that the size of the global maritime economy will reach $3T within the next decade, with blue economy solutions taking up an increasing share of the market.[128] At current projected growth levels, the U.S. is expected to continue to lose market share and comprise 20% of the overall blue economy market in 2030.

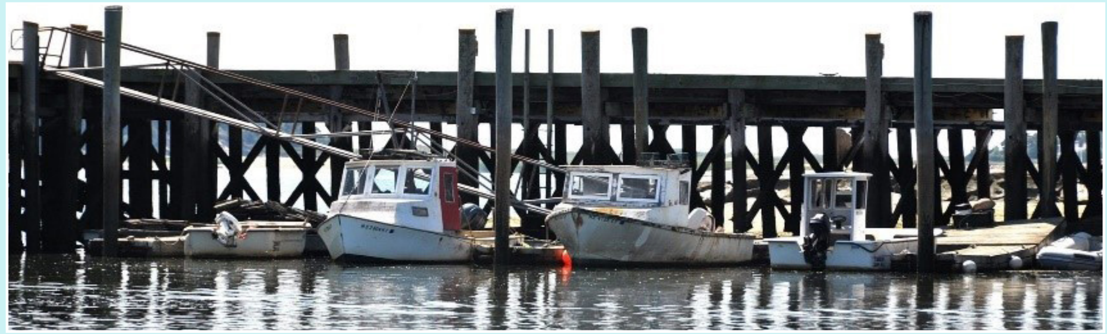
In the U.S., the private sector has been the main driver of R&D, accounting for 83% of the growth in R&D investment between 2010 and 2019. Today, the private sector contributes 71% of all R&D. The U.S. government's support for R&D has increased, but not as rapidly, as its share of funding support is now only 21% of that total. In terms of the innovation pipeline, the U.S. government is the largest source of funding for basic research (41%), while business accounts for the majority of funding for applied research (58%), as well as experimental development (90%).[129]

During its tenure, the Biden Administration has increased investment by 9% to $171B. Of that, two-thirds are invested in defense and health R&D.

The three main public sector funders of blue R&D are:

- **NATIONAL SCIENCE FOUNDATION** (NSF): $400M
- **NOAA**: $251.5M
- **DOE WATER POWERS TECHNOLOGY OFFICE**: $179M

Other U.S. government agencies and offices devoted to expanding and exploring the blue economy include: the Maritime Administration in the Department of Transportation, the International Trade Administration in the Department of Commerce, and the Office of Economic Growth, Energy, and the Environment in the DOS.



Cape Cod Blue Economy Foundation. (Source: The Foundation)

There are many cross-sector research projects that may contribute to ocean research, but at a minimum, the U.S. federal government is currently investing over $830.5M in ocean, coastal, and freshwater sciences. Factoring in business investment, the total water industry R&D spend for the U.S. is approximately $3.01B.

Mapping the U.S. Blue Innovation Ecosystem

There are multiple established maritime clusters in the U.S. These clusters are located at strategic ports and hubs on or along the Pacific and Atlantic Oceans, the Gulf of Mexico, and the Great Lakes. In many cases, the anchor institution in these hubs combines catalytic, basic research, applied research, and incubation capabilities.

For example, in New England, the **GULF OF MAINE RESEARCH INSTITUTE** has advanced understanding of quantitative fisheries research, fisheries ecology, and pelagic fisheries, and has created **GULF OF MAINE VENTURES** to support forty-one start-ups in the area. Their partner, **SEAAHEAD**, has also established an incubator and innovation showcase capability, as well as mobilized capital to support fifty-one start-ups.

There are many other research and innovation bridge organizations throughout New England, such as the **CAPE COD BLUE ECONOMY FOUNDATION**, which focuses on education and workforce opportunities. One of their hallmark events is "**WATERWORKS**," a career showcase for connecting high school students to the blue economy and Science, Technology, Engineering, and Mathematics (STEM) career opportunities in the Cape Cod region. WaterWorks activities include demonstrations, exhibits, interactive displays, and hands-on activities for investing in the future workforce and exciting students about these emerging fields.[130]

Other important anchors around the country include:

San Diego

THE SCRIPPS INSTITUTION FOR OCEANOGRAPHY at University of California San Diego is a global leader in marine research and conducts extensive analysis on the following core themes:

- Resilience to Hazards,
- Human Health and the Oceans,
- Innovative Technology,
- Polar Science,
- Biodiversity and Conservation, and
- National Security.

In addition, it has created the **STARTBLUE** accelerator in partnership with the Rady School of Management. They have helped incubate over eighty new start-ups directly, and their work supports a regional workforce of nearly 46,000 individuals and over 1,400 companies producing $14B in direct sales.

Since its formation in 2015, the **BLUE ECONOMY INCUBATOR** at the Port of San Diego has developed multiple pilot projects, including:

- a unique cleanup solution to extract toxic contaminants from impacted marine sediment,
- the first worldwide installation of an innovative and scalable bio-enhancing shoreline stabilization technology, and
- a portable five-in-one field-testing sensor to provide real-time metals analysis during stormwater monitoring.

The incubator has also established collaborative partnerships with numerous local, state, and federal governmental agencies, academia, NGOs, industry, and the local community.

San Diego is also home to **TMA BLUETECH™**, a regional nonprofit trade association that hosts BlueTech Week.

"The Sunken Seaweed Pilot Farm" project at the Blue Economy Incubator at the port of San Diego.

(Source: Port of San Diego)

Hawai'i

THE HAWAI'I NATURAL ENERGY INSTITUTE (HNEI) at the University of Hawai'i at Mānoa has a history of conducting R&D in the sectors of wave energy and Ocean Thermal Energy Conversion (OTEC).[131] Currently, they are contributing to two wave energy projects and providing research support to the U.S. Navy Wave Energy Test Site (WETS).[132] They are also working on the HNEI-led **HAWAI'I WAVE SURGE ENERGY CONVERTER** (HAWSEC), which could produce cost-effective renewably generated electricity for coastal communities.[133]

Hawai'i is also home to the **NATURAL ENERGY LABORATORY OF HAWAII AUTHORITY**, powered by the Hawaii Ocean Science & Technology Park (HOST). The State of Hawai'i has invested $100M since 1974 to create the HOST Park.

HNEI-led HAWSEC.

(Source: HNEI)

South Florida

The Harbor Branch Oceanographic Institute at Florida Atlantic University (FAU) contributes to the growing field of AUV technology and research, with the goal of improving the efficiency, frequency, and depth of underwater exploration missions. Scientists at Harbor Branch develop and use AUVs to collect oceanographic data and study marine ecology, such as deep-water coral reefs, features of the seafloor, and endangered fish species.[134]

Also based in Miami, the **SEAWORTHY COLLECTIVE** is a 501©3 BlueTech or "ocean innovation" start-up incubator & community. To date, they have supported eight solutions for coastal resilience and adaptation, seven for pollution, and six for greenhouse gas reduction and removal.

Analysis: "The Blue Economy Ecosystem in the United States"

While space precludes this report from summarizing all the innovation hubs across the country, there are several important data points to take away from this ecosystem.

It is decentralized and "messy" – in some places like the Gulf of Maine or Chesapeake Bay, it is natural to have dedicated and focused programs targeting local conditions. However, in many cases, researchers and entrepreneurs are tackling overlapping problems, needs, and issues. Programs across the U.S. are addressing resilience, pollution, and aquaculture sectors. There is a built-in competitive framework.

A major limiting factor is the scale of water-based research. Complex fluid dynamics, enormous space for species maps, crushing ocean depths, and boundarylessness are just a few of the challenges that researchers much overcome.

There is an increasing emphasis on idea conversion. Many academic and research institutions have developed partnerships with venture capitalists and entrepreneurs to develop incubators and accelerators. In particular, there is a symbiotic relationship in California between university faculties and commercial business developers.

Pipeline support is critical. Factors like blue economy workforce development, access to capital, quality research infrastructure, open channels of communication, convenings, and PPPs are all vital components of the overall success of innovation hubs.

Lastly, there is a lot of "good" failure in the U.S. innovation ecosystem. The famous inventor, Thomas Edison, once remarked that experiments that did not turn out well were not failures. Rather, they helped advance understanding of what did not work. Similarly, many of the U.S. innovation hubs support pilots and start-ups for which there may not be a clear market, but still help to advance intriguing ideas that future researchers or start-ups might be able to build upon. ●

U.S. BLUE INNOVATION CLUSTERS

BOSTON

- Cape Cod Blue Economy Foundation
- Sea Grant at the Massachusetts Institute of Technology (MIT)
- Northeast Center for Coastal Resilience at the University of Massachusetts Amherst

GULF COAST

- Dauphin Island Sea Lab
- Gulf Blue at the University of Southern Mississippi
- Texas OneGulf Center of Excellence

HAWAII

- Hawai'i - Conservation International
- Hawai'i Natural Energy Institute at the University of Hawai'i at Mānoa (UHM)
- Hawai'i Sea Grant at the University of Hawai'i

PACIFIC NORTHWEST (OREGON AND WASHINGTON)

- Blue Innovation Hub (BIH) at Oregon State University's Impact Studio
- Washington Maritime Blue
- Maritime Innovation Center (MInC) at the Port of Seattle
- Northwest (NW) Center of Excellence for Maritime Manufacturing & Technology

SOUTH FLORIDA

- Harbor Beach Oceanographic Institute at Florida Atlantic University
- Marine Research Hub
- National Coral Reef Institute (NCRI) at Nova Southeastern University (NSU Florida)

SOUTHERN CALIFORNIA

- AltaSea at the Port of Los Angeles
- Blue Economy Incubator at the Port of San Diego
- StartBlue Program at the University of California San Diego

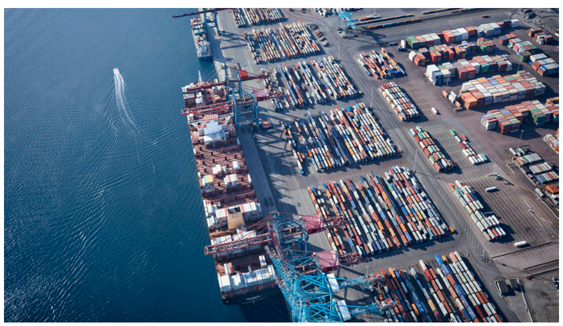
6 The Blue Economy Ecosystem in Sweden

With only 0.13% of the world's population, Sweden has had a remarkable global impact in many research fields and commercial disciplines. While Sweden has a global leadership position when it comes to funding R&D, its commitment to all of its support systems that undergird innovation pipeline development is far-reaching. This begins with its kindergardten through twelfth (K-12) education system, its commitment to national broadband, and its cultural predisposition to promote international dialogue and information exchange, as embodied by the prestigious Nobel Prizes that it presents annually.

As of 2020, Sweden spends 3.5% of its GDP on R&D, ranking fourth in the world after Israel, South Korea, and Chinese Taipei. Sweden was the first country to pass an environmental protection act in 1967 and has maintained a leadership role in championing the environment ever since. Sweden ranks number one in the Global Green Economy Index[135] and fifth in the Environmental Performance Index.[136]

Blue innovation is part of the country's overall commitment to innovation and to the environment.

Sweden has the most integrated green economy on the planet. This means that environmental considerations are built into Swedish commerce and industry as a core principle. For example, Swedish industry leaders like Volvo, Ikea, and H&M are committed to circularity and being climate positive. The Ports of Stockholm have committed to zero fossil fuel emissions by their truck fleet by 2025 and to be entirely fossil fuel-free by 2030 at the latest. In 2016, the Gothenburg Port Authority assumed the chair of the sustainability committee of the **EUROPEAN SEA PORTS ORGANIZATION**, and has played an important role in championing Europe-wide measures to enhance the sustainability of port operations. According to the UN Educational, Scientific, and Cultural Organization (UNESCO), Sweden has the third-highest density of marine scientists in the world.



The Port of Gothenburg is the largest port in Scandinavia, with nearly 30% of Sweden's exported goods passing via its quays.

(Source: Port of Gothenburg)

TOWARDS A SUSTAINABLE BLUE ECONOMY IN SWEDEN

The Stockholm Environment Institute's March 2023 study "Towards a Sustainable Blue Economy in Sweden" provides an impressive snapshot of the Swedish blue economy and blue innovation agenda.

Their findings include:

- Around 10,000 metric tons of fish, crustaceans, and molluscs are grown for consumption annually. There are roughly fifty food fish farms in Sweden and just as many hatchery fish farms.
- Catches in commercial fishing in the sea in 2021 amounted to just over 138,799 metric tons of live weight. This is a reduction by about 18,000 tons, or 10%, compared with 2020.
- During 2020, around 28 terrawatt-Hour (TWh) of wind power was produced in Sweden (compared to 3.5 in 2010), of which around half a TWh was made up of offshore wind power from Lillgrund, Kårehamn, Vindpark Vänern, and Bockstigen.
- 40,000 jobs are connected to maritime tourism, whereas Baltic Sea locations represent around three-quarters of the labor market.
- Although building on a small base, in 2018, the Maritime Innovation Index moved from 100 (base year 2016) to over 200 for 2018.
- From 2000 to 2016, Sweden registered 230 ocean renewable energy inventions, ninety-three ocean pollution abatement inventions, and forty-four coastal adaptation inventions. In total, 417 ocean-related environmental technologies were accredited to Swedish inventors, which placed the country in the fourteenth position out of 121 countries.

As of 2021, Sweden's blue economy employs 119,000 people and generates over 61.B SEK. Since 2009, Sweden's blue gross value added (GVA) has increased by 42.7%. Its blue economy is dominated by coastal tourism, which contributed 68.4% to blue jobs and 59.8% to GVA in 2018. Maritime transport and marine living resources follow as other important sectors, contributing nearly 15.1% in blue jobs and 21.5% of GVA.[137]

To support the growth of the nation's blue economy, in 2021, the Swedish Government set aside 1.214T SEK for R&D, including 16.7B SEK for general environmental protection and nature conservation.[138]

Research Field	Funding Amount (SEK)
Oceanography, Hydrology and Water Resources	127,069,405 kr.
Marine Engineering	4,000,000 kr.
Ocean and River Engineering	4,270,000 – 9,155,771 kr.
Water Engineering	132,861,811 – 139,852,082 kr.
Water Treatment	9,406,301 – 31,123,250 kr.
Fish and Aquacultural Science	35,458,598 – 38,758,385 kr.
Total	**313,066,115 – 349,958,893 kr.**

Public Funding Amounts (SEK) for Swedish Research Projects by Research Field, 2022[142]

The Swedish Agency for Marine and Water Management (SwAM) has outlined the following environmental focus areas:

- Zero Eutrophication,
- Flourishing Lakes and Streams,
- A Balanced Marine Environment, and
- Flourishing Coastal Areas and Archipelagos.[139]

SwAM's other priorities and concerns for Swedish waters and the Baltic Sea include: acidification (mostly caused by forestry), depleted fishing stocks, eutrophication and drainage of sewage, effects of hydropower, international collaboration (including the Helsinki Convention, or HELCOM, for the Baltic Sea environment), and healthy drinking water sources (such as Vänern, Vättern, Mälaren, Hjälmaren, and Storsjön lakes).[140]

Research projects in 2022 were publicly funded in the following fields:[141]

- Oceanography, Hydrology, and Water Resources,
- Marine Engineering,
- Ocean and River Engineering,
- Water Treatment, and
- Fish and Aquacultural Science.

This funding was provided by the following agencies:

- **FORMAS**, the Swedish Research Council for Sustainable Development,
- **VINNOVA**, Sweden's innovation agency, and
- **THE SWEDISH RESEARCH COUNCIL**, the largest governmental research funding body in Sweden.

Mapping the Swedish Blue Innovation Ecosystem

Sweden's innovation pipeline also closely links basic research to commercialization. Both the University of Gothenburg and Chalmers University of Technology have venture creation arms, with Gothenburg's dating back to the 1990s. Another interesting facet is that western and eastern Sweden's profiles are very different because the conditions posed by the North Sea/Atlantic Ocean versus the Baltic Sea are so different. Western Sweden is the industrial and logistics hub of the country, while Eastern Sweden is the touristic hub.

Sweden is home to sixty-four incubators and science parks.[143]

Important anchors for Sweden's innovation pipeline include:

STOCKHOLM

THE STOCKHOLM INTERNATIONAL WATER INSTITUTE (SIWI) was founded in 1991 with the inaugural World Water Week and Stockholm Water Prize. As a global leader in water governance, SIWI envisions a "Water Wise World" in which the value of water is understood, and therefore, it is inclusively shared and used sustainably.

WORLD WATER WEEK is an annual conference hosted by SIWI. Conference highlights include SIWI Scientific Seminars, the Accelerator program for capacity-building, and the presentation of the Stockholm Water Prize.

THE DIVISION FOR WATER AND ENVIRONMENTAL ENGINEERING AT KTH ROYAL INSTITUTE OF TECHNOLOGY seeks to increase knowledge and improve the use of natural and technical systems for water, land, and geological resources via research and education. The division's key competencies include: water and soil chemistry, hydrogeology, water and wastewater technology, and blue growth. It also has pilot-scale laboratory facilities at Hammarby Sjöstadsverket.

The Port of Nynäshamn is located 60 kilometers south of Stockholm city and is both a modern passenger and Roll-on, Roll-off port. (Source: Port of Nynäshamn)

GOTHENBURG

OCEAN DATA FACTORY SWEDEN is national marine data lab in Sweden working to enable data-driven innovation by commercial and non-commercial stakeholders for the sustainable management of the ocean and its resources. The Factory conducts activities in fast-paced "innovation cycles" focused on a use case and involving internal consortium work, open workshops and events, and open dissemination of findings.

- Their seventh and most recent cycle, the "Do-It-Yourself" Challenge, started in January 2023 and focuses on building and deploying ocean sensors.
- They are supported by Vinnova and the EU European Regional Development Fund.

THE DEPARTMENT OF MARINE SCIENCES AT THE UNIVERSITY OF GOTHENBURG hosts several other marine research and innovation centers at the University, including: the **CENTRE FOR SEA AND SOCIETY, LINNAEUS CENTRE FOR MARINE EVOLUTIONARY BIOLOGY, MARINE INFRASTRUCTURE RESEARCH, R/V SKAGERAK, TJÄRNÖ MARINE LABORATORY,** and **KRISTINEBERG CENTER FOR MARINE RESEARCH AND INNOVATION**. They are the main applicant for the research program "Co-Creating Better Blue."

- **CO-CREATING BETTER BLUE** is a research program consisting of thirty-eight marine stakeholders – thirteen research organizations and twenty-five stakeholders from industry, authorities, and civil society.
- It focuses on three thematic pillars: Science, Technology, and Governance and Management.
- The program receives 50M SEK over four years from Mistra under their "A sustainable blue economy for Sweden" program, as well as an additional 4M SEK in co-financing from Region Västra Götaland region and 8M SEK from other actors.

GU VENTURES is an incubator that helps to build up seed- and early-stage ventures primarily in life science and technology. It works closely with the University of Gothenburg, and its portfolio of blue companies includes **OSTREA AQUACULTURE** and **SEATWIRL**.

THE PORT OF STOCKHOLM also engages with EU projects, partnerships, and networks for sustainability and benefitting the environment.[144]

Current projects include:

- Coordinated supply of onshore power in Baltic seaports (2020 – 2024)
  - This project brings together the four Baltic Sea Ports of Stockholm, Copenhagen/Malmö, Aarhus, and Helsinki for investing in onshore power connections that supply electricity to cruise ships, thus reducing emissions of air pollutants from shipping within port areas.
  - Supporters of this project include the Connecting Europe Facility (CEF) program within the EU, as well as the Swedish Environmental Protection Agency's Climate Leap program.
- Upgrade of the Baltic Sea Bridge Kapellskär–Naantali – MoS Finnlink (2020 – 2023)

SWEDISH BLUE INNOVATION CLUSTERS

GOTHENBURG

- Department of Mechanics and Maritime Sciences at Chalmers University of Technology
- OffshoreVäst
- SARGASSO
- University of Gothenburg Centre for Sea and Society

MALMÖ

- Blue Green City Lab
- Maritime Education Center
- World Maritime University

NORRKÖPING

- Sjöfartsverket, the Swedish Maritime Administration
- Swedish Meteorological and Hydrological Institute

STOCKHOLM

- Division for Water and Environmental Engineering at KTH Royal Institute of Technology
- Global Water Partnership (GWP) Global Secretariat
- Swedish Agency for Marine and Water Management (SwAM)
- Stockholm University Baltic Sea Centre

- The Ports of Kapellskär in Sweden and Naantali in Finland are participating together in this project to strengthen links between the two ports.
- Project benefits include: investments in facilities to supply onshore electricity to quayside vessels, reduction in vessel air pollutant emissions in port areas, installation of an auto-mooring capability, and a new passenger tower.
- Supports of this project include CEF.

Analysis: "Mapping the Swedish Blue Innovation Ecosystem"

The Stockholm Environment Institute has pointed out several challenges with the Swedish system. For example, the last offshore wind power installation was deployed in 2013. There are currently eight licensed wind farms at sea (or in large inland lakes), but none of these have yet been put into use. There are several projects at different stages of the planning process, both for anchored and floating wind structures, in more than forty locations. Also, there is currently no testbed able to cope with entire value chains for offshore innovations. Most testbeds focus on technical efficiency of individual components, but there is a need to explore technical transfer across sectors.[145]

These issues point to the fact that there are many competing claims about what is environmentally positive, which can affect government regulatory processes and lead to a certain amount of paralysis. Similarly, the research challenges posed by various environmental issues can require expensive and complex investment.

One of the most important questions to resolve is how to integrate Sweden's innovation pipeline into the larger EU context. There are several areas where Sweden could lead scientifically and commercially that would capitalize on its environmental cultural base and provide dividends to the EU. Already with industries like marine spatial planning, digital twinning, and shipping, Sweden is leading international dialogues and promoting pan-Baltic and pan-European cooperation.

Compared to the U.S., Sweden does not have the financial resources to make huge investments, and yet, it certainly holds its own. This is due in part to its culture, its early and strong commitment to technology, and its global outlook. As a country of 10.5M people, it does not have internal markets large enough to scale global companies. Its ability to understand conditions and needs in Europe, the U.S., and elsewhere have enabled it to have a large global footprint relative to its size. This idea generation function is a competitive advantage.

Sweden illustrates that innovation pipelines are not just dependent on funding, but also on how funding and the innovation process are structured. ●

Recommendations for Sustained Blue Innovation

In 2020, the peer-reviewed Proceedings of the National Academy of Sciences published the following:

"The current scale, pace, and practice of ocean scientific discovery and observation are not keeping up with the changes in ocean and human conditions. We need fundamental changes in the way that researchers work with decision makers to co-create knowledge that will address pressing development problems.[146]

Doubling current blue R&D and innovation support is economically justified given the environmental costs and market opportunities that have been identified. However, innovation is not just a question of funding - it is a mindset, as well as a commitment to explore alternative strategies and new solutions.

Based on this analysis, the following recommendations would help to jumpstart more blue innovation.

Strengthen Research and Innovation Catalysts

- All sectors should develop catalytic tools to raise awareness about pressing research questions, both in terms of environmental challenges and market opportunities.
- Governments should create policy frameworks that incentivize private capital investment, innovation prizes, specialized journals, international conferences, education and workforce development programs, and other support systems for innovation pipelines.

- All sectors should consider developing catalytic incentives, such as the creation of prizes patterned after those like the Nobel Prize and Ocean Observing Prize, competitions, hackathons, and so on.
- A blue innovation pipeline index should be developed that supports national:
  - needs identification and prioritization,
  - funding requirements versus budget,
  - basic research funding and productivity,
  - applied research,
  - experimental design,
  - entrepreneurship support and new business development, and
  - new product development.

Support Basic Research

- Governments should benchmark their current blue innovation R&D budgets and increase support for basic research to 50%, 75%, or 100% of best-in-class R&D funding levels. These investments should be indexed to projected costs and CAGR forecasts.
- Governments should not pick winners and losers, but rather, encourage competitions, diverse approaches, and multiple innovation hubs to flourish.
- Support must grow for drones, sensors and other monitors, and digital tools that can expand data coverage to measure essential variables related to water dynamics and ocean processes across all sectors.
- Greater development is needed for new tracking and prediction capacities that support integrated and multi-hazard early warning systems, improved community preparedness, and greater awareness across all sectors.
- Efforts must advance towards building "digital twin" models of flooding, drought, and extreme storm conditions that leverage machine learning, AI, and the latest innovations in information technology that should be embraced across all sectors.

Strengthen Applied Research, Experimental Design, and New Business Development

Specifically:

- the relationship and alignment between identification and prioritization of blue economy needs and public sector basic research investments,
- cross-sector and cross-industry dialogue, information-sharing, and network opportunities, and
- incubator and accelerator support systems and capabilities leveraging ports, industrial parks, research parks, and other facilities.
- After-action reviews and criticisms of existing approaches should by systematized across sectors. Catalysts for new ideas should be embraced in a spirit of promoting continuous improvement.
- "Failure" should be redefined as an important tool of the learning process, while "fast failure" that encourages pilots, prototypes, trials, and other initiatives that promote rapid learning should be embraced.

Build Up Pipeline Support Capabilities

Specifically:

- encourage the development of water-themed educational materials for K-12 curricula,
- support workforce development programs such as apprenticeships, community college and undergraduate programs, and advanced degree programming that includes financial support for students from lower-income or otherwise disadvantaged or underserved backgrounds,
- encourage corporate R&D, venture funds, and intrapreneur programs,
- facilitate business, academia, and public sector dialogues, showcases, and information-sharing opportunities, and
- encourage private capital formation and deployment for water R&D.

As can be seen from this report, both the U.S. and Sweden have pursued similar models to foster basic research, applied research, and experimental design across a range of environmental challenges and industry opportunities. Both have high-intensity public sector research budgets, academic engagement, and significant business investment. And yet, significantly more investment should be taking place. Developing an integrated and structured innovation pipeline agenda would deliver many benefits and assist with future resilience, adaptation, and sustainable development.

Reducing the economic impacts of global water challenges by even 10% would yield approximately $30-50B in annual cost savings. Increasing the productivity and scale of the maritime sector by 10% would yield over $183B in new revenues. The case for investing in blue innovation speaks for itself. ●

Appendix

Kind Designs Co-Founders James Layfield and Anya Freeman (2nd and 5th from left, respectively) pictured with event hosts and speakers. (Source: SACC-USA)

Blue Innovation at Work:
November 4, 2022 Climate Technology Showcase

ISD, SACC-USA, the U.S. Embassy in Sweden, and Hummeltorp Sverige AB hosted "The Power and Promise of the Blue Economy" on November 4, 2022, in Fort Lauderdale, Florida. The hallmark of the event was the Climate Technology and Innovation Showcase, in which representatives from five blue economy start-ups pitched their ocean solutions to and received feedback from a curated judges' panel.

The "Hummeltorp Evolution Award 2022," including a $5,000 cash prize, was awarded to Kind Designs by Hummeltorp for their innovative "3-D Printing technology that prints living seawalls that mimic coral reefs and mangroves, hosting biodiversity and improving the quality of water."[147] Hummeltorp created the Evolution Award 2022 to spotlight those disrupting the status quo of climate technology and to encourage and scale up ideas for tackling climate change.

In addition to Kind Designs, the companies below represented other industries like ship emissions capture, desalination, weather and ocean alkalinization, and marine recovery of minerals and gasses.

- **BOND ENERGY** is working to "make desalination more economically viable by commercializing the extraction of elemental resources from seawater."
- **GREENER PROCESS SYSTEMS** hosts "patented, state-of-the-art technology to capture and reduce air pollution from oceangoing ships docked in ports to near zero."
- **LILLY1 TECHNOLOGY'**s enhanced weather and ocean alkalinization enhancement tech "works with nature to maximize its potential without creating more problems in the process."
- **SOONER MINERAL RECOVERY, INC.** catalyzes "innovation for sustainable & economical commodity extraction" and has been working on new tech for the "gating of divalent cations for commercial purposes."

Innovation showcases like these help the entrepreneurs, judges, companies, and investors in attendance, as well as support the diffusion of innovative ideas to stakeholders who can build on them.

List of Acronyms and Their Meanings

AI	Artificial Intelligence
ANC	Active Noise Control
AUV	Autonomous Underwater Vehicle
B	Billion
BIH	Blue Innovation Hub
CAGR	Compound Annual Growth Rate
CCUS	Carbon Capture, Utilization, and Storage
CEF	Connecting Europe Facility
CFI	Coastal Fisheries Initiative
CO2	Carbon Dioxide
CSO	Civil Society Organization
CSR	Corporate Social Responsibility
C2B2	Co-Creating Better Blue
DOD	United States Department of Defense
DOE	United States Department of Energy
DOER	Deep Ocean Exploration and Research
DOS	United States Department of State
DSM	Deep-Sea Mining
EPA	United States Environmental Protection Agency
ESG	Environmental, Social, and Governance
EST	Energy Saving Technology
EU	European Union
EU27	The 27 European Union countries following the UK's departure in 2020
FAO	United Nations Food and Agriculture Organization
FAU	Florida Atlantic University
GDP	Gross Domestic Product
GEF	Global Environment Facility
GEF TF	Global Environment Facility Trust Fund
GOA-ON	Global Ocean Acidification-Observing Network
GVA	Gross Value Added
GW	Gigawatts
GWP	Global Water Partnership
HAWSEC	Hawai'i Wave Surge Energy Converter
HELCOM	Helsinki Convention
HIV	Human Immunodeficiency Virus
HNEI	Hawai'i Natural Energy Institute
IMO	International Maritime Organization
ISD	Institute for Sustainable Development
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
ITIF	Information Technology & Innovation Foundation
K-12	Kindergarten Through Twelfth Grade
KAUST	King Abdullah University of Science and Technology
km	Kilometer
kWh	Kilowatt-Hour
LDC	Less-Developed Country
LNG	Liquid Natural Gas
LWCF	Land and Water Conservation Fund
M	Million
MInC	Maritime Innovation Center
MIT	Massachusetts Institute of Technology
MW	Megawatts
NCCR	Northeast Center for Coastal Resilience
NCRI	National Coral Reef Institute
NGO	Non-Governmental Organization
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
NSU	Nova Southeastern University Florida
NW	Northwest
OA	Ocean Acidification
OECD	Organization for Economic Co-operation and Development
OTEC	Ocean Thermal Energy Conversion
PCB	Polychlorinated Biphenyls
PPP	Public-Private Partnership
RAMSSES	Realization and Demonstration of Advanced Material Solutions for Sustainable and Efficient Ships
R&D	Research and Development
SACC-USA	Swedish-American Chambers of Commerce of the USA, Inc.
SDG	Sustainable Development Goal
SEK	Swedish Krona
SIDS	Small Island Developing States
SIWI	Stockholm International Water Institute
SRC	Stockholm Resilience Centre
SSE	Shore-Side Energy
STEM	Science, Technology, Engineering, and Mathematics
SwAM	Swedish Agency for Marine and Water Management
T	Trillion
TWh	Terrawatt-Hour
UHM	University of Hawai'i at Mānoa
UK	United Kingdom
UN	United Nations
UNDNRR	United Nations Office for Disaster Risk Reduction
UNEP-FI	United Nations Environment Program Finance Initiative
UNESCO	United Nations Educational, Scientific, and Cultural Organization
U.S.	United States
UUV	Unmanned Underwater Vehicle
WASH	Water, Sanitation, and Hygiene
WEF	World Economic Forum
WETO	Wind Energy Technologies Office in the U.S. DOE
WETS	United Nations Navy Wave Energy Test Site
WMO	World Meteorological Organization

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