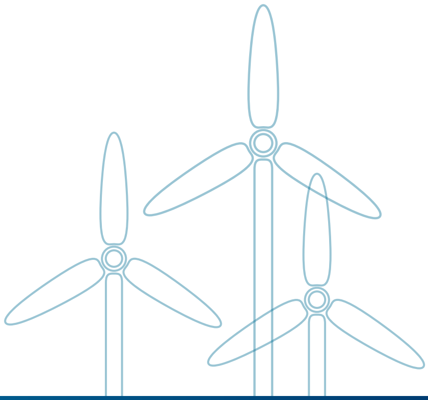
COMPETENCE NETWORK SUBSEA@FRAUNHOFER

SMART OCEAN TECHNOLOGIES
SOLUTIONS FOR RESPONSIBLE OCEAN USE



SUMMARY

White areas on maps have long since become a thing of the past. The Earth has been mapped and explored down to the utmost detail... with one major exception: the depths of the ocean. We know less about it than we do about the dark sides of the Moon and Mars. Thorough knowledge would be prudent here, after all, as growth on land is increasingly approaching its limits. Humans are already using the ocean in a growing number of ways: It serves as a transportation route; fiber-optic cables routed across the ocean floor make high-speed internet possible; aquaculture operations provide a source of food; and the ocean is also seeing increased industrial use through offshore wind farms and oil platforms. This is why developing appropriate ocean technology is extremely important. Society, policy and business depend on the results of oceanic research – only with the necessary knowledge can the oceans and seas be protected and sustainably used. Oceanic research is also a powerful driver for developing cutting-edge maritime technology, whether it be sensor systems, underwater vehicles or deep-sea observatories.

One field research by itself rapidly reaches its limits for developing ocean technology. The Subsea@Fraunhofer competence network founded in 2016, on the other hand, combines the extensive experience and expertise in the field of subsea technology from a total of 13 Fraunhofer institutes and facilities, taking research in this seminal field to a new level. This makes the competence network Europe's leading network for applied research in subsea technology, justified above all by its unique selling point: Subsea@Fraunhofer studies the entire spectrum of ocean and subsea technology. It is multidisciplinary and includes experts in IT, materials science, engineering, electronic systems, sensor technology, power engineering, robotics, aquaculture, automation technology and systems engineering.

The ocean technologies that are being developed need to satisfy virtually opposing requirements: intervening in the oceanic ecosystems as little as possible while still answering a diverse range of relevant questions and uncovering complex interrelationships. Oceanographers seek to manage this balancing act in different areas of research, one being in the base technology. Developing underwater vehicles, for example, with the appropriate power supply, novel sensors and robust, high-resolution imaging. Other areas of research focus on communication, navigation and manipulation while under water. These base technologies, however, are not the only important aspect: Cross-sectional technology is essential for successful and sustainable ocean use. This includes the development of smart services, which make an important contribution to value creation in the maritime industry, or reliability, such as for offshore applications.

With its expertise, the Fraunhofer-Gesellschaft is helping develop technology for the "smart ocean" and convert the developments into application. In short, it is taking an active part in establishing a balance between use and conservation of the ocean, with the development of appropriate technologies going hand in hand with innovative, internationally active maritime industrial companies. These technologies include infrastructures for testing and startup as well as for three-dimensional acquisition and monitoring of large underwater structures, such as offshore installations.

How can we use the ocean responsibly? Fraunhofer's Subsea network is answering this question with concrete recommendations.

INTRODUCTION

When seen from space, the Earth beams predominantly a magnificent blue. This is because around 70 percent of its surface is covered by ocean. And although we humans think we know our planet pretty well, we know little about these "blue" areas. Humans do, however, know very well how to use the ocean: It provides food, energy and raw materials, can be used as a transportation route and is an indispensable part of the Earth's climate system. Humans will soon begin using the ocean even more. The question, then, is how can we use the ocean's resources efficiently and responsibly while still protecting the marine environment? This balance between economic exploitation and marine conservation is what is motivating the researchers at Fraunhofer and must be the basis of future developments.

Underwater use poses major challenges to technology

The seas are home to rough conditions: Wind and storms whip over the surface, saltwater corrodes materials, pressure rises the deeper down you go, and much more. This poses serious challenges to humans and technology. And when the technology is meant to be used under water, the challenges are disproportionately higher. Wireless communication under water, for example, is only possible to a very limited extent. Broadband solutions like WiFi cannot be used to connect robots, equipment and operators. This is because electromagnetic waves are dampened too much under water. Modems, which rely on acoustic signals, only allow for very low bit rates. Underwater systems thus need to be autonomous or research needs to find a way to develop broadband, wireless communications technology.

Robots under water not only are supposed to communicate with each other, they must also know their exact location. This kind of self-localization is the basis for numerous applications, such as charting or docking maneuvers, making it a core component of mobile robotics. On land, satellite-based navigation systems such as GPS solve this navigation issue in many applications. Indoor navigation systems have wireless technology at their disposal. Under water, however, these global positioning systems have so far proven to be unfeasible. For this reason, solutions such as sonar and acoustic logging, which need to be set up locally, and inertial sensors and communication with surface vessels are currently being employed. Improving the quality of underwater navigation will require novel approaches in the areas of sensor technology and sensor fusion.

A number of tasks in the underwater arena also require the analysis of imaging data, such as surveying tasks or the evaluation of flora and fauna in oceanography. In offshore areas, visibility can drop to below one meter, making the use of optical cameras less than ideal. In order to complete more demanding tasks, we need new, high-resolution environment detection sensors along with processes for improving the images captured. Alternative approaches are high-resolution, acoustic 3D camera systems or even laser scanners with enhanced imaging ranges.

Even underwater conditions themselves – high water pressure, saltwater, biofouling from prolonged exposure as well as strong and unpredictable oceanic currents – require specific and rugged solutions. These have so far only been realized for niche applications and at high cost.

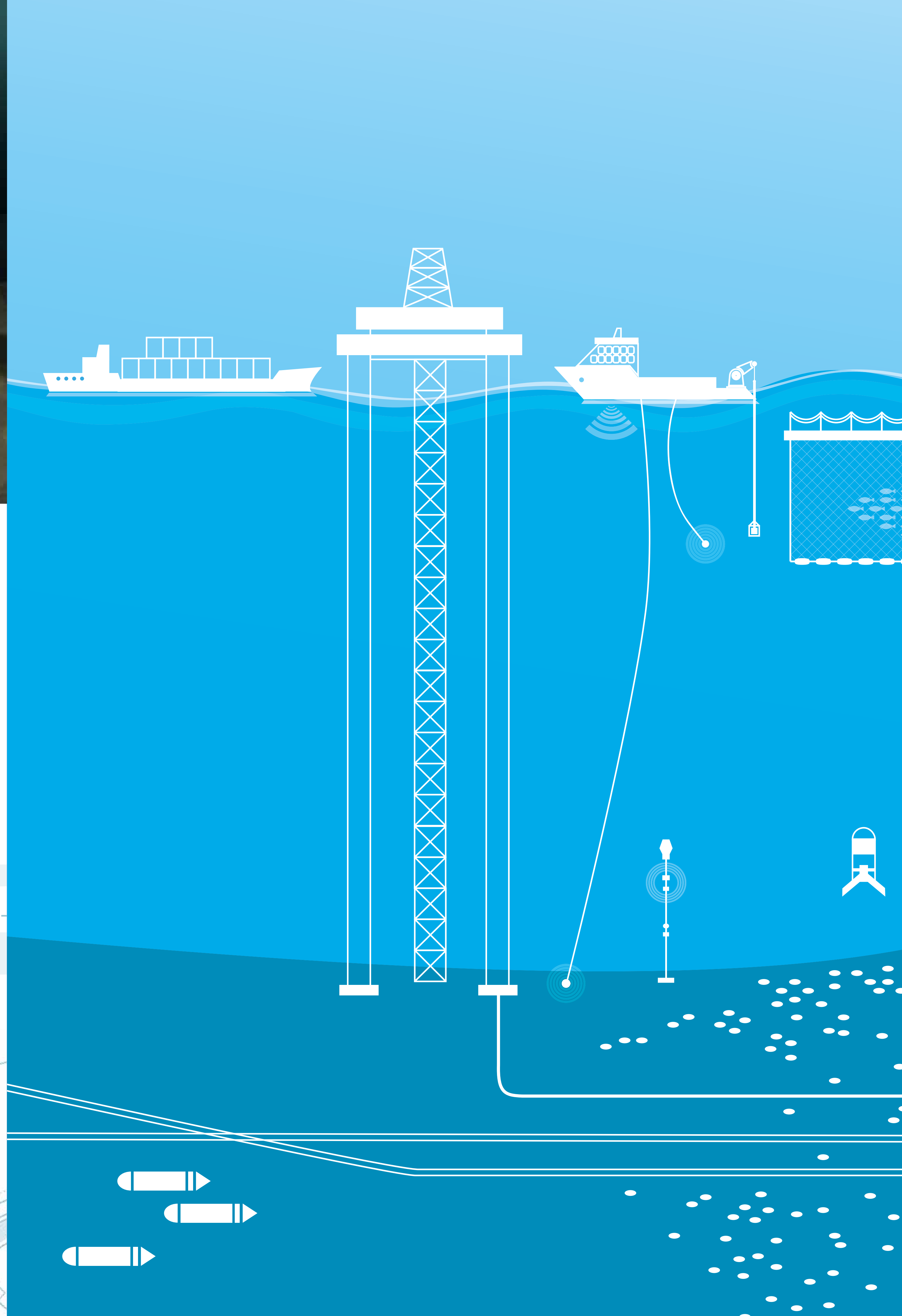
How can technology be used in underwater environments despite all of these obstacles? The competence network Subsea@Fraunhofer is developing the proper solutions and technologies to answer this question.

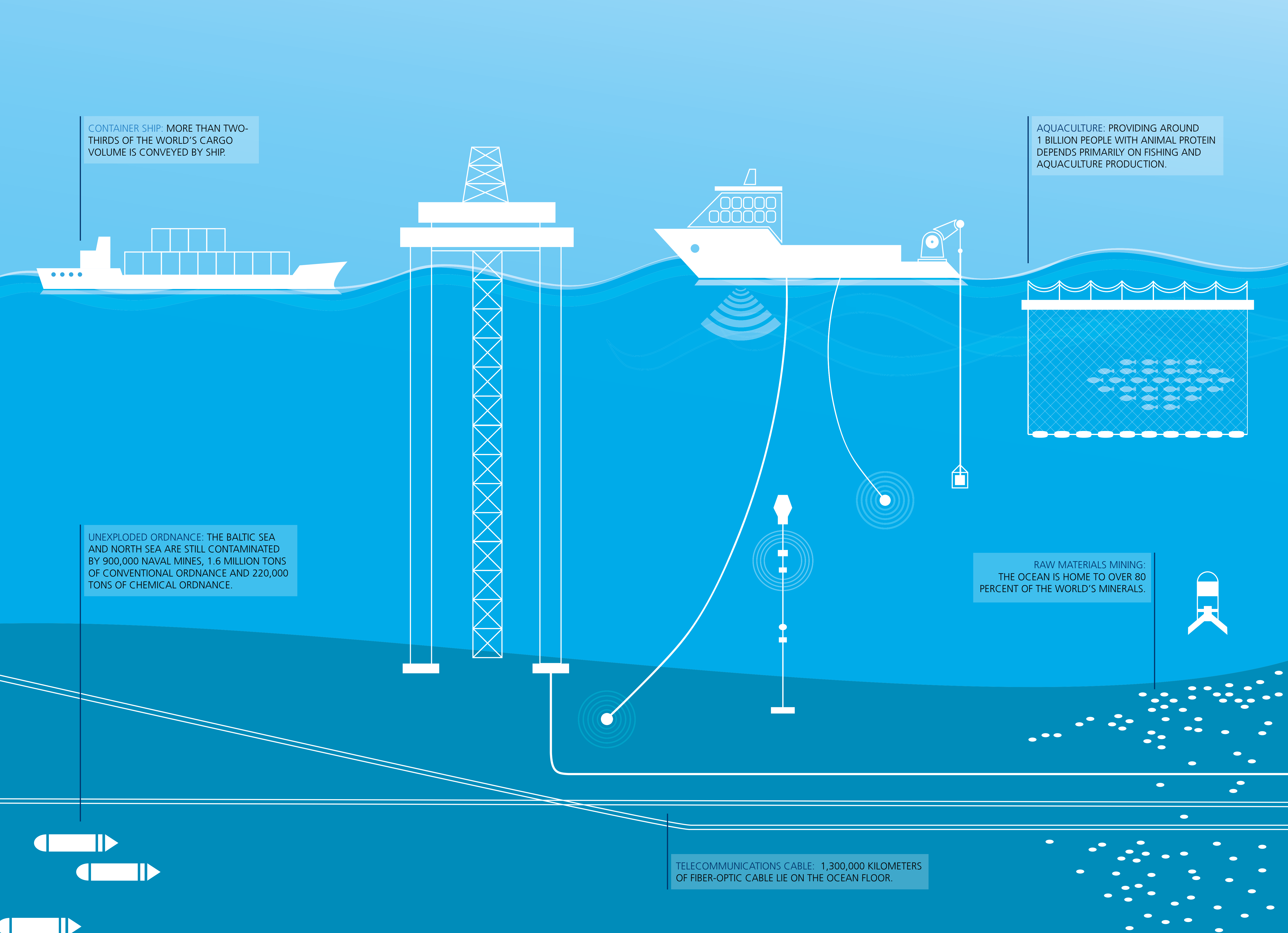
Ocean use is changing

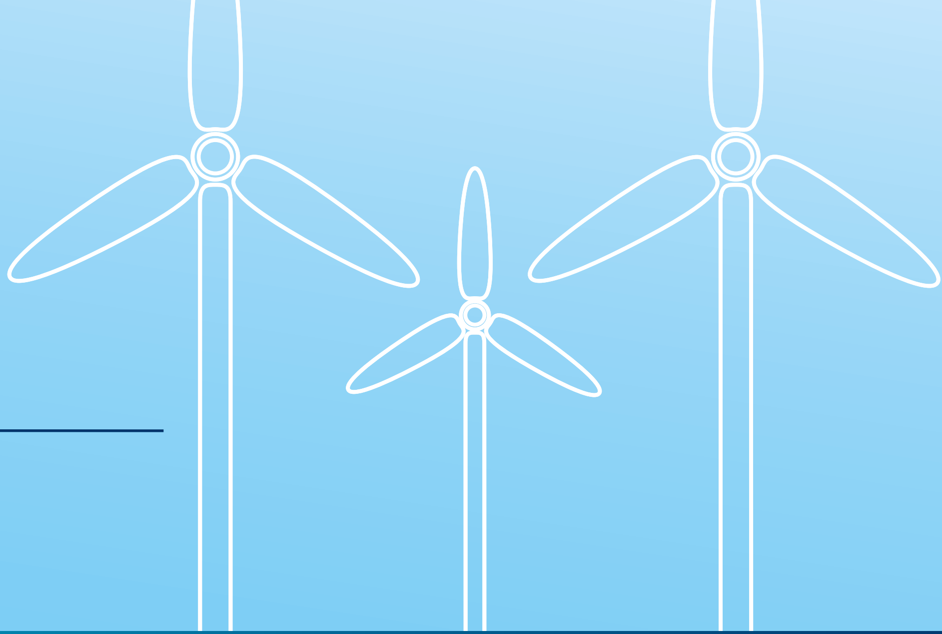
Humans have been using the ocean since the dawn of time. How it is used, however, has changed through the ages. Even today, future changes have begun to emerge. It can thus be expected that ocean use will occur at an ever-growing distance from shore. Oil and gas production, offshore wind farms and even, for example, aquaculture operations will not be located near the coast. Having humans on these installations will therefore become very expensive and hazardous. Due to weather conditions, it will also not be possible year-round to reach the installations by ship.

Even the deep sea is becoming increasingly important in terms of economic exploitation and research. Since humans can no longer work directly in this inhospitable environment, numerous technologies that make possible partially/fully autonomous systems will see growing use in the underwater environment.

For example, in the future, entire oil, gas and mineral installations will be set up on the ocean floor. The initial visions of companies operating in these industries show installations on the order of large cities. However, the necessary technology to construct, operate, inspect and remove these installations has yet to be developed. Technology similar to that used for these production installations will be needed for large-scale, long-term ocean observatories for both oceanography and monitoring of environmental standards for forms of economic exploitation.




CONTAINER SHIP: MORE THAN TWO-THIRDS OF THE WORLD'S CARGO VOLUME IS CONVEYED BY SHIP.
AQUACULTURE: PROVIDING AROUND 1 BILLION PEOPLE WITH ANIMAL PROTEIN DEPENDS PRIMARILY ON FISHING AND AQUACULTURE PRODUCTION.
UNEXPLODED ORDNANCE: THE BALTIC SEA AND NORTH SEA ARE STILL CONTAMINATED BY 900,000 NAVAL MINES, 1.6 MILLION TONS OF CONVENTIONAL ORDNANCE AND 220,000 TONS OF CHEMICAL ORDNANCE.
RAW MATERIALS MINING: THE OCEAN IS HOME TO OVER 80 PERCENT OF THE WORLD'S MINERALS.
TELECOMMUNICATIONS CABLE: 1,300,000 KILOMETERS OF FIBER-OPTIC CABLE LIE ON THE OCEAN FLOOR.



OFFSHORE INSTALLATION: EUROPE HAS 4,543 WIND TURBINES IN 11 COUNTRIES WITH A TOTAL OUTPUT OF 18,500 MW (AS OF THE END OF 2018).

AREAS OF APPLICATION

Humanity stands before significant challenges, such as the future supply of energy, raw materials and food. The ocean is playing an increasingly important role in overcoming these challenges. It is fundamental to look at such future applications, technologies and foreseeable development paths in a comprehensive manner. Only in this way can synergistic potential be exploited and the research activities of the various institutes be coordinated with one another.

The ocean as a food source

The world's population is constantly growing. More than 8 billion people will be living on our planet by 2025. A study by the world food organization FAO shows that agricultural production will need to increase more than 70 percent by 2050 compared to 2005, assuming a world population of 10 billion. Aquaculture and especially mariculture will therefore play a decisive role in the future. One example is the Aquapod system: This self-sufficient, sphere-like cage with a diameter between 30 and 60 meters is placed far from the coast and produces large quantities of fish in a highly automated and sustainable fashion. Even combinations of the numerous offshore wind farms and aquaculture operations could be promising. The first test installations have already been set up. The algae spirulina also offers plenty of potential with regard to feeding the world's population: This organism's protein production per unit area is 20 times that of soy, 40 times that of corn and 200 times that of beef. Production does not require a lot of space and can even use saltwater and wastewater.

The ocean as a communication channel

Our world is increasingly connected. This is due to high-speed internet. Hubs are connected largely by fiber-optic cables laid deep on the ocean floor. These make possible the communication of data over great distances while being considerably less expensive than satellite-based communication. The propagation delay of the signals is also lower. However, deep-sea cables are difficult to modify, maintain and expand. Overall, the global network is over 1.3 million kilometers long and is getting longer every day. Around 97 to 99 percent of the world's data traffic runs through cables in the world's oceans. Even power cables are being placed more and more on the ocean floor.

The ocean as an energy source

Without offshore wind power, Germany's Energiewende cannot succeed, as it is a critical pillar. There are 1,305 offshore wind farms in Germany alone, generating 6,380 MW of power. By 2025, it is predicted that expansion will have increased this figure to 10,800 MW. The country with the most output from offshore wind farms in the world is Great Britain, followed by Germany and, at a distant third, China. If Germany seeks to maintain its technological leadership in the domain of offshore wind power, efforts must be increased in the area of research and development: Costs of generating power must decrease considerably – for example, through efficient maintenance – in order for Germany to be competitive.

The ocean as a source of raw materials

Natural gas and oil have been obtained from the ocean for over 100 years, with an increasing trend: The number of extraction sites in the ocean has grown from around 500 in 1990 to over 4,000 in 2015. However, since many low-sea deposits have already been depleted, we are pushing into greater and greater depths. Whereas there were only a few deep-sea drilling sites at the end of the ’90s, the percentage in 2015 was already at 30 percent, with the assumption that two-thirds of all deep-sea deposits have yet to be discovered. In addition, marine mineral resources will become important: Over 80 percent of the world’s minerals are found in the ocean. To make use of marine resources in an environmentally viable way requires new maritime technologies. The high-tech research vessel “Sonne,” for example, is helping to answer scientifically and socially relevant questions, primarily regarding the supply of marine raw materials and human intrusion on ecosystems.

The ocean as a transportation route

The seas are an essential transportation route for international trade: More than two-thirds of the world’s cargo volume is transported over the ocean and the trend is growing. However, due to the limited appeal of the occupation, it is increasingly difficult to find nautical personnel. One way out is the unmanned ship, which will initially be controlled remotely from land or at least monitored, and which will, in the next phase, run all on its own. Industry estimates show that these autonomous ships could be in operation by 2035. Transport via the ocean, however, cannot be done by ships alone. Undersea pipelines are also used worldwide to transport oil and gas, with over 9,000 km of new pipeline installed between 2012 and 2017 alone.

The ocean as a garbage dump

The ocean is heavily polluted and contaminated – over 70 percent by plastic. Predictions indicate the amount of plastic in the ocean will increase threefold between 2015 and 2025. Where all this plastic resides in the ocean is largely unknown and must be urgently studied. Chemical substances from a broad range of sources are also collecting in the ocean, with the most dangerous being substances that take a long time to degrade, accumulate in animals and are, moreover, toxic. International guidelines are necessary here, which, in turn, require an intensified level of study. Even unexploded ordnance is a problem. The North and Baltic Seas, for example, continue to be contaminated by 900,000 naval mines, 1.6 million tons of conventional and 220,000 tons of chemical ordnance. This greatly jeopardizes the economic exploitation of these seas as well as presents danger to human life and the environment.

AREAS OF RESEARCH

The use of the ocean is becoming more diverse and comprehensive. Since the ocean is of great importance to the ecosystem of the Earth, this use must be extremely responsible. This is only possible through the development of new technologies, such as those able to gauge their ecological footprint themselves. The requirements of such technology are high. It can only be allowed minimal intrusion in marine ecosystems, needs to detect environmental hazards and identify their origin, facilitate the establishment of environmental constraints and monitor their compliance, and also be able to speedily reduce and remove environmental hazards. It should also make possible fundamental exploration of the complex interrelationships and effects of biological systems in the ocean, of the climate-related processes in the ocean, and of the unknown regions of the ocean. This technology should also increase the safety of the humans working on and in the ocean, one example being remote-controlled or autonomous underwater systems performing hazardous tasks in inhospitable environments.

BASE TECHNOLOGIES

The Fraunhofer institutes possess a broad range of technological expertise for addressing the previously mentioned areas of application. Through targeted research, these fields of technology will be consistently expanded.

Vehicles

To be able to use the ocean in the future in a sustainable and economically sensible way, the level of automation of technical systems needs to increase. Robots, for example, need to be able to work autonomously even in the deep sea. The highest rates of growth in the commercial sector may be in autonomous underwater vehicles (AUVs), which will become the universal carrier platform for sensors and manipulation systems such as robotic arms and tools. This will require them to always be able to perform their tasks autonomously, that is, without monitoring ships or operators. Only then can they be meaningfully and cost-effectively employed, and be able, for example, to map large areas of the seafloor or inspect, maintain and even remove infrastructure. One building block of implementation is docking stations (underwater garages), where the AUVs can autonomously enter, recharge their energy storage system, exchange data and then continue with their mission. Pressure-neutral technology is also extremely important, considering the enormous pressure prevailing in the ocean depths. This is why sensors and electronics are in demand that can withstand this pressure – without the need for an external pressurized casing – and thus be operable at any ocean depth. Pressure-neutral power supplies and batteries also improve system reliability.

Energy storage systems

Energy storage systems are essential for long-term operation. These limit not only operating times but also the ability to carry additional sensors or manipulators. And naturally, energy storage systems, such as batteries, for example, impact the size and weight of the carrier systems. The challenge is to increase the capacity and energy density of these energy storage systems while minimizing charging times, weight and size. This is because the requirements for such systems are constantly increasing. Another promising concept would be to obtain the energy from directly where it is needed – the marine environment – through a process known as “energy harvesting.”

Sensors

Sensors are the eyes and ears of underwater installations, as it were, and are indispensable when it comes to measuring, charting and even navigation tasks. It is imperative to continuously improve the accuracy of sensors, as this can have a significant impact on the success and quality of a mission. Another development challenge lies in novel sensors to accomplish tasks that are currently impossible, such as penetrating deep into the seafloor, generating high-resolution 3D imaging data in harsh environments, detecting explosives electrochemically or measuring the concentration of microplastics – all without the detour to a laboratory on land. Imaging plays a fundamental role in learning more about the deep sea. In many cases, however, optical systems are of no use: In deep-sea mining, for example, sediment is heavily churned up, leaving little to detect with optics alone. Three- or even four-dimensional sonar imaging, on the other hand, makes possible resolutions in the centimeter range even in poor visibility. Research teams are currently working to improve image quality and increase refresh rates. More compact systems should permit integration into underwater vehicles.

Underwater communication

Underwater communication is a crucial part of marine engineering. Robotic systems, measurement platforms and submersibles need to be able to communicate data with the operator or to each other. This is the only way complex missions, including in schools of fish, can be efficiently completed. Robust and, if possible, broadband communication that is also wireless is an important prerequisite for numerous underwater engineering applications..

Underwater navigation

On land, high-precision navigation systems have become commonplace. In the future, a navigation system similar to GPS, with similar accuracy and coverage, will also be needed under water – deep in the ocean. This kind of system is needed not only to explore the ocean but also for the increased installations of structures that are being built in it. These can be offshore energy installations as well as underwater plants for extracting oil and gas or other raw materials. In the harsh underwater environment, these structures need to be constantly maintained and inspected if they are to function continuously and reliably. Precise navigation is a prerequisite for using robotic systems.

Underwater manipulation – teleoperated and autonomous

The robotic systems need to not only inspect these kinds of underwater structures but also occasionally step in and make repairs, such as removing overgrowth, replacing subcomponents, welding, cutting, and collecting and transporting all kinds of samples. To accomplish all this, the vehicles require flexible, multipurpose manipulators.

Underwater joining

Whether harbor facilities, dams or foundations for wind turbines – the service life of hydraulic engineering structures can be up to 50 years. For this reason, various attachments need to be replaced, repaired or upgraded over the course of this service life – all under water. Yet, welding and mechanical joining processes are difficult under water and result in various problems such as leaks, corrosion, etc. Fraunhofer researchers are developing adhesive joining processes that are suitable for different base materials.

CROSS-SECTIONAL TOPICS

The Subsea@Fraunhofer competence network is not only working on base technologies. The strength of the network rather lies in its multidisciplinary structure and the broad expertise of the institutes and researchers involved. This expertise includes IT, materials science, engineering, electronic systems, sensor technology, power engineering, robotics, aquaculture, automation technology and systems engineering – covering a broad range of technologies. The result: Subsea@Fraunhofer has all the expertise needed to develop high-quality, complete systems. Because adequately meeting the challenges in the field of maritime technology makes networked collaboration essential. These challenges demand approaching the topic from a wide variety of fields and combining different approaches.

Smart services – from data to added value

How do you bridge hardware for underwater use and value creation in the maritime industry? One important pillar is smart services. With extensive expertise in information processing, Fraunhofer is helping its customers refine raw data into tailored, value-added services. To achieve this, the data must be managed and processed so users can derive the fastest possible decisions from it and be able to access the data again at any time. The data may occasionally even need to be analyzed in real time, which would be essential for mobile systems, in particular, to adequately react to events. Fraunhofer's portfolio covers the entire processing pipeline, from efficient acquisition, storage and management of data to quality assurance, to interactive visualization or fully automated data analysis. These services form the basis for new business models in the dawning age of digital underwater technology.

Reliability: quality is the clincher

For offshore applications, in particular, being able to maximize the reliability of installations is highly relevant, as access to these installations is not possible at every time of year and under all weather conditions, which limits maintenance. Offshore technology must therefore be reliable and long-lasting. Fraunhofer offers a wide range of methods that can be adapted directly to these specific requirements, such as nondestructive processes or structural mechanics simulations.

Simulation: from theory to practice

A deep understanding of the physical principles is the prerequisite for qualifying technologies for underwater use. The experts at Fraunhofer possess this expertise and use it to routinely push the limits of the feasible – whether the propagation of sound through water or steel, or the hydrodynamic behavior of vehicles in a current. Theory, models and simulations always form the starting point for practical solutions.

WHAT THE FRAUNHOFER-GESELLSCHAFT CONTRIBUTES

The ocean is gaining international importance when it comes to economic development. At the same time, it has a decisive effect on the climate of the Earth and has a sensitive ecosystem. From this comes an enormous responsibility for the sustainable use of the ocean. New technologies that make this responsible use possible need to be developed now. At the Fraunhofer-Gesellschaft, we possess much of the necessary expertise in our various institutes. There is now a once-in-a-lifetime opportunity to develop technologies for the "smart ocean," convert them into application and thus take an active part in shaping the balance of exploitation and conservation of the ocean. The know-how of Subsea@Fraunhofer will help translate very solid robust and reliable technologies into application. This is exactly what is decisive for use in the ocean and this prospect is extremely interesting to the Fraunhofer-Gesellschaft, given the highly multidisciplinary nature of maritime technology and the very specific profile of the institutes. Germany has an innovative, internationally involved maritime industry that, together with Fraunhofer, can develop and market these new technologies "Made in Germany."

INFRASTRUCTURES FOR TESTING AND STARTUP

When components or complex systems need to be used for industrial underwater applications, they first need to be put through their paces. However, efficient testing options that cover all the relevant tests have so far been lacking. Subsea@Fraunhofer has been planning a science and industry center for underwater technology in the Baltic Sea that will be the first of its kind in the world. The researchers at Rostock's Digital Ocean Lab will not only work on classical underwater technology but also develop and test sensors, autonomous vehicles, underwater robotics, and processes for underwater image processing and visualization. In addition, Subsea@Fraunhofer is combining the previously isolated infrastructures at the other locations into a virtual testing center, which is intended to establish ideal general conditions for the research and development of underwater technology as well as close the existing gaps. A complementary concept for a testing center in the North Sea near Helgoland is currently being drawn up with the future users. The technical emphases here will be materials research, offshore engineering and maintenance concepts for underwater structures.

RESEARCH AND TECHNOLOGICAL DEVELOPMENT

Subsea@Fraunhofer covers a wide range of underwater technologies. This means there are numerous research projects being worked on in the network and new areas of application are opening up, such as submersible drones and sensors of every type.

Carrier vehicles: from low sea to deep sea

Underwater vehicles designed also to explore the deep sea need to be reliably controlled. For more than 10 years, Fraunhofer has been working on appropriate control systems, resulting in years of experience. Developments include both remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs). One example is the AUV known as DEDAVE, which can dive up to 6,000 meters. Unmanned surface vehicles (USV), in turn, are used wherever submersible vehicles can no longer be of assistance – primarily in coastal or harbor areas. The HydroCrawler,

for instance, monitors environmental and safety aspects in these areas, both to protect nature and humans. Fraunhofer is able to develop complete vehicle concepts, build them to order and custom-equip them with sensors.

Capturing and monitoring large underwater structures in 3D

Offshore installations, dams and other underwater structures need to be inspected regularly. This has been done primarily by submersibles, since conventional sensors lack precision, resolution, speed and data quality. To address this, Subsea@Fraunhofer is developing multimodal sensor systems, including innovative laser scanners, stereo camera-based imaging systems and high-resolution sonar systems. This reduces both the effort and the costs of underwater inspections.

INDUSTRY'S PARTNER FOR INNOVATION

Fraunhofer sees itself not only as a developer of marine technology but also as taking on an important role as a partner for innovation with industry. Fraunhofer researchers initiate and moderate innovation processes, and support businesses on complex research projects. This is best illustrated by an example, such as the Munitect network. Instigated by Fraunhofer in cooperation with the Maritime Cluster Northern Germany, the network currently comprises 18 partners from industry and research. Its goal: to develop an economical sensor system for reliably tracking down unexploded ordnance in the seas. At present, only small areas can be scanned at random, with a detection rate of just 80 percent. To avoid dangers to humans and the environment, the seas need to be comprehensively searched and cleared. With cost-effective sensor platforms, this should become possible and economically viable.

In what direction is the field of maritime technology developing? To industry, this is a fundamental question. One that is answered by industry-wide technology roadmaps, which are created in conjunction with industry players in places such as conferences. This is why Subsea@Fraunhofer has partnered with Germany's Federal Ministry for Economic Affairs and Energy and the German Association for Marine Technology to launch the MAROS (Marine Robotics and Sensors) conferences that have been held every two years since 2011. The goal is to help small and medium-sized enterprises also gain access to the international market. The value creation chains may also be interesting to businesses that, until now, were not active in the maritime sector. Furthermore, the maritime industry can also be a potentially new area of business for established companies in other domains.

POTENTIAL FOR INDUSTRIAL AND RESEARCH PROJECTS

Fraunhofer has completed scores of research and development projects over the years. Despite this extensive prior experience, we are only at the start of development. Many technologies that are self-evident on land are technically not yet available today due to the special conditions under water.

These include:
- Wireless broadband communication over great distances
- Vehicles that can stay underwater and reliably function for several years
- Comprehensive access to energy (fueling/charging stations)
- Robotic systems for maintaining and repairing underwater structures
- Affordable drones that are easy to operate and that complete monitoring reliably and efficiently or inspection tasks with a high degree of autonomy
- Smart materials that integrate diverse functions into a single material, adapt their properties to different usages, and can be easily worked using 3D printing processes
- Open and compatible standards for underwater technologies

Some topics already have concrete starting points today – others still need new stimulus from basic research. With broad technological expertise and experience in multidisciplinary research and development, Fraunhofer prevails over the ideal conditions for facing the technical challenges of underwater technology.

FRAUNHOFER SUPPORTS BUSINESSES AND PUBLIC ENTITIES:

As a pool of experts for exploring technologies and areas of application.

As a strategic partner for R&D, from basic research to product development.

With access to laboratories and test benches.

By licensing existing technologies developed by the institutes.

Through active networking of research and businesses.

RECOMMENDATIONS

Whether food production, raw materials production or energy production – the use of the ocean by humans will soon increase greatly. Given this, Subsea@Fraunhofer network has drawn up the following recommendations:

- **Research and development of underwater technology must be intensified** because the use of the ocean must occur with an extremely high level of responsibility. This makes it essential to develop underwater technologies that preserve the balance between the economic exploitation of marine resources and conservation of the marine environment – completely in line with the International Decade of Ocean Science for Sustainable Development called by the United Nations for 2021 – 2030.

- **Testing and proving possibilities for underwater technologies must be expanded** because it is the only way reliable and robust systems can be efficiently developed for use in the real world.

- **Unexploded ordnance in the North and Baltic Seas must be comprehensively found and removed** because this longstanding pollution poses an extreme danger to humans and the environment, and the economic exploitation of the ocean will be greatly limited.

- **A European partnership for deep-sea mining must be established and initially publicly funded** because it will allow Europe – and, with it, the marine technology in Germany – to achieve technological leadership in sustainable, environmentally friendly deep-sea mining and we can make ourselves, as a country with few natural resources, strategically more independent.

- **International standards for underwater missions must be introduced** because only then will the interaction of a wide variety of technologies during complex missions be effectively possible and technology development be strongly promoted. This will also ensure the sustainable use of the ocean.

- **A legal framework for the use of autonomous underwater vehicles must be created** because this will develop legal certainty, which is necessary to allow the use of autonomous systems for economic exploitation on a large scale.

If Germany's industry and research landscape tackle together the challenges that accompany the growing use of the ocean, there is a real opportunity to be able to achieve a long-term competitive advantage in this growth market.

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