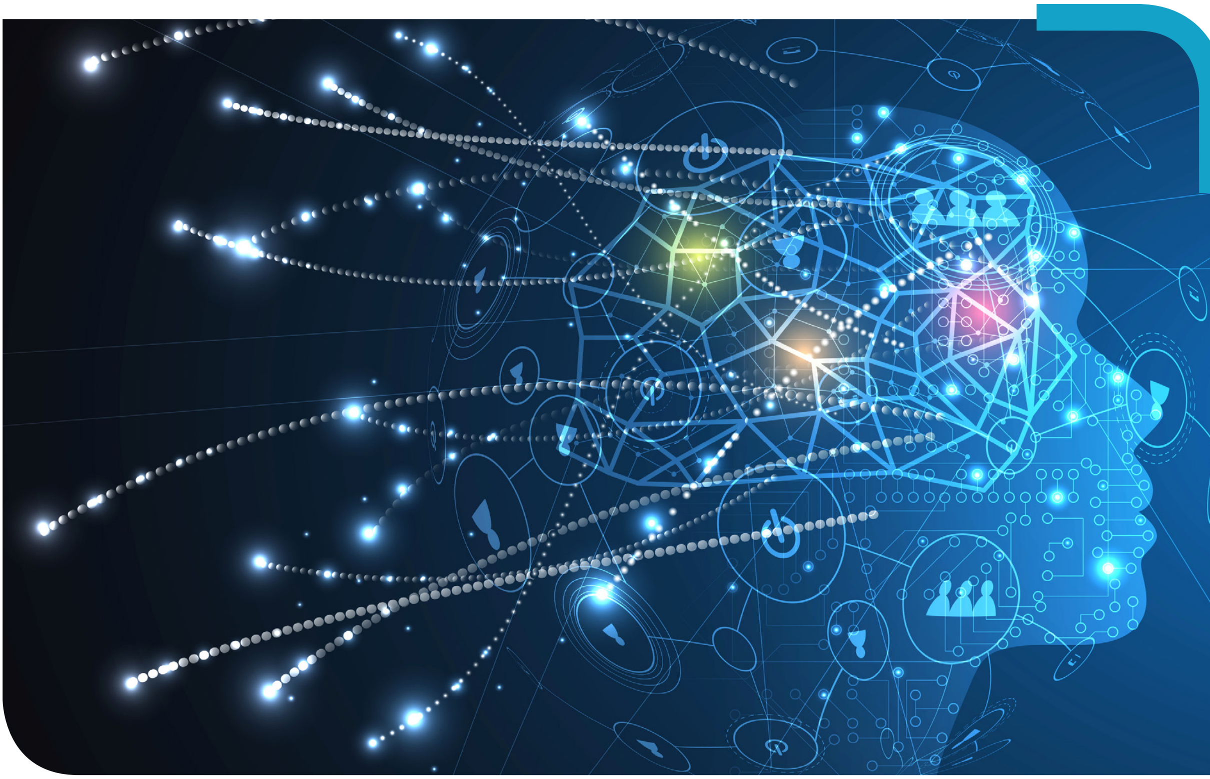
BLUE TECHNOLOGIES FOR BLUE SUSTAINABILITY

OCEAN AND SEAS: CHALLENGES AND SOLUTIONS



INTRODUCTION: INNOVATIVE OCEAN TECHNOLOGIES FOR BLUE SUSTAINABILITY

Blue economy is predicted to be an important driver for economic growth in the coming years, with a shift towards innovative and sustainable solutions. At the same time, ocean and seas play a major role in climate regulation. With this vision document, the Blue Cluster of Flanders and the Flanders Marine Institute (VLIZ) elaborate with key experts on the importance of innovative ocean technologies to reach the Sustainable Development Goals (SDGs). Blue technology and innovation will not only contribute to SDG14 (Life Below Water) but certainly also to many others (see box text).

Ocean and seas provide huge potential for large-scale production of **renewable energy** (wind, but in the future also wave, tidal, floating solar etc.), can counterbalance droughts and fresh water shortage by **desalination-**installations, and nature-based solutions can **protect coastal areas**. Moreover, **clean shipping** will be an indispensable element to come to a carbon neutral transport system.

From a technological point of view, combining technology and smart sea solutions is key for success. From a policy perspective, mangement tools such as marine spatial planning (**MSP**) are instrumental to explicitly provide space for blue innovation projects. The future-oriented way forward is a clustered approach, where all actors from the quintuple-helix - companies, scientific institutes, policy makers, society and nature - work together towards integrated, underpinned Science, Technology and Innovation (STI) solutions. The ocean as a common good gives us the responsibility to increase actions to come to sustainable and climate neutral solutions for society.

DESALINATION: INSTRUMENTAL IN THE FRESH WATER CHALLENGE

In the 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, Clean Water and Sanitation was defined as a sustainable development goal. It is stated that safe drinking water and sanitation are basic human rights. Access to fresh water, in sufficient quantity and quality, is also a prerequisite to achieving many dimensions of sustainable development, including health, food security and poverty reduction. In 2015, 5.2 billion people (71 per cent of the global population) used safely-managed drinking water services - that is, an improved water source located on premises, available when needed and free from contamination. An additional 1.3 billion people (17 per cent of the population) used a basic drinking water service - an improved water source not more than 30 minutes away. This means that 844 million people still lacked even a basic level of service.

DESALINATION IS EXPECTED TO PLAY A KEY ROLE IN NARROWING THE WATER DEMAND-SUPPLY GAP.

It is generally accepted that conventional water resources are no longer sufficient to meet the rising water demands. Hence, approaches such as desalination are expected to play a key role in narrowing the water demand-supply gap. At present, it is estimated that around 16,000 desalination plants are active, producing 95 million m^3/day of desalinated water for human use.

The main types of desalination methods are membrane desalination (such as Reverse Osmosis), and thermal desalination. In thermal desalination, heat is used to evaporate water, to condense it and to purify it. Reverse osmosis (RO) desalination is based on a pressure-driven separation technology principle to remove salt and other impurities by passing water through a series of semi-permeable membranes. Since its development approximately 70 years ago, this membrane technology has evolved into the leading desalination method. The basic efficiency of the RO-process in itself is already very high and the expectation is that future developments and technological challenges towards a higher economic and ecological sustainability will focus on three pathways, namely the evolutions in the membranes themselves, the creation and deployment of hybrid desalination systems and the creation of intelligent, linked systems. These three evolutions are interlinked, not only between themselves, but also with the wider pursuit of solutions, insights and societal challenges of the water supply chain.

THREE PROMISING INNOVATION PATHWAYS ARE IDENTIFIED: EVOLUTIONS IN THE MEMBRANES THEMSELVES, CREATION AND DEPLOYMENT OF HYBRID DESALINATION SYSTEMS AND INTELLIGENT, LINKED SYSTEMS.

Improvements in the membrane technology in the coming period for the membranes mainly relate to increasing water permeability and improved mass transport properties. In addition, it is also expected that the price of the membranes will fall in the future, either because the production volumes will increase or because new, cheaper technologies will be developed for their manufacture.

Apart from the technological and economic optimisation of the processes, there are significant societal challenges linked to desalination. Desalination is not an isolated issue, but it has an impact on our environment: through the energy used, the residual products and its place in the broader water supply landscape. Considering the impact on the environment, a number of key challenges need to be addressed: the saline concentrate and chemicals discharges (the so-called brine) to the marine environment, the emissions of air pollutants and the energy demand of the processes. Therefore, innovative technologies and strategies are highly needed to mitigate the environmental impact and reduce the economic cost of brine disposal. In this regard, promising progress is being reported by recent studies, where it is stated that the produced brine may be converted into useful chemicals and can even contribute to the efficiency of the desalination process, through the use of hybrid systems.

Hybrid desalination technology involves combining two or more processes in order to achieve better environmental solutions and a reduction in production costs, compared to each individual process. Hybrid can be seen as the combination of regular power plants and thermal desalination plants, where thermal energy from the power plant drives the desalination. Such installations are operational on a large industrial scale. Other sources of energy and

combinations are also possible: developments in so-called Salinity Gradient Power (SGP), where energy can be produced through the combination of two water masses with a higher (e.g. seawater) and lower (e.g. riverine discharge) salinity. This technology has shown to work at a pilot stage to both produce energy and lower the salinity of the input stream, and as such providing a pre-treatment for the desalination through reverse osmosis, leading to possibly lower energy demand and associated costs and reduced environmental impact.

Although effective cleaning protocols have been developed and applied in RO-desalination plants, at last the membranes have to be replaced. In this sense, it is estimated that more than 840,000 end-of-life RO-membrane modules (> 14,000 tons of plastic waste) are discarded in landfills every year worldwide. This points towards the need for further research and development, to strive towards a fully circular economy approach for RO-technology, leading to alternatives to end-of-life RO-membranes management, following the hierarchy of priorities for waste treatment (prevention, reuse, recycling and, eventually, disposal).

Finally, desalination is not an isolated activity, but belongs to a water system, and as such, a system approach is needed. The need for pure (drinking) water is part of a broader societal demand for water. Agriculture, industry, shipping, the ecological well-being of our watercourses: all need water to a greater or lesser extent, at the same or at different times, each with its own requirements with regard to the water quality. The mapping (in space and time) of these water needs, so that there is a clear view of the water demand, is a first step in this approach. Desalination can and will be part of this water puzzle, along with other technologies and methods such as reusing process water or adapting infrastructure for large-scale rainwater buffering. One of the major technological challenges of the next 10 years therefore lies in making optimal use of the available water resources, based on actual needs. Smart desalination systems will be a part of this and can be developed for this purpose, so that production, storage and use can be optimally matched to fit the water system. Those desalination systems can consist of series of small, interlinked and locally-specific desalination systems, or larger-scale systems, which may also be located at sea.

The realisation and implementation of linked solutions for water demand, and the use of desalination technology in this, requires a great deal of political and social effort and the necessary support for building such infrastructure will need to be backed by sustainable technology that can guarantee that the methods are economically interesting, with the least possible impact on the environment. Hybrid systems, which reduce the costs and environmental impact of desalination through smart coupling, will evolve further over the next 10 years towards a larger-scale roll-out and realisation of interconnected systems.

MSP AS A TOOL FOR INNOVATION AND COLLABORATION

Ocean and seas are drivers for the economy and have great potential for innovation and growth. All economic activities that relate to ocean and seas are collected in the term 'blue economy' and the associated growth, often driven by innovation, is referred to as 'blue growth'. According to the OECD, the output of the ocean economy could double by 2030. Nevertheless, sustainable development of the ocean calls for a more strategic and integrated approach to its planning. Marine Spatial Planning (MSP) is increasingly gaining importance as a tool that can guide and support a sustainable blue growth. It is widely used to efficiently allocate space among several competing activities, whose socio-economic benefit is at stake, while at the same time safeguarding the environment.

Blue economies are expected to grow and MSP can play a significant role in this process. A direct impact of MSP can be as catalyst for innovative high-tech solutions. By identifying suitable test beds and demonstration sites, MSP provides space for innovative technologies to be tested and as such, it facilitates the process of their de-risking. Such examples include the space for testing an autonomous shipping route between Finland and Sweden; Portugal providing space for four ocean multi-use demonstrator sites; the Netherlands having the Offshore Innovation Lab where innovative and combined technologies are being tested. As such, MSP ensures that the future potential of the ocean is also considered in today's planning. Besides, MSP can undoubtedly increase the stability, transparency and predictability of the investment climate where they are implemented. MSP is a forward-looking process which facilitates employment of future technologies (e.g. floating energy islands or autonomous shipping) by already considering their spatial implications in the planning process. Furthermore, the changes in ship sizes and shipping efficiency may completely change the pattern of shipping as we see it now (including the spatial requirements for ports and shipping lanes).

MSP CAN DE-RISK THE DEPLOYMENT OF NEW TECHNOLOGIES BY ASSIGNING APPROPRIATE SPACE FOR TEST BEDS & DEMONSTRATION SITES.

MSP can provide the ground for realistic visions - and thus offer the roadmap for such visions to come true. Innovation and technology development may not

be understood as hardware only - but also in view of social and business model innovations. As such, MSP can be a key enabler to move away from single-sector thinking towards more system, circular and life-cycle design thinking. By inspiring co-use applications, MSP may also lead to a new understanding of the relationship between different sectors as well as industry and society. Consequently, this may have impacts on and support the development of technologies which combine multiple applications at the same time.

Being a stakeholder-driven process, MSP is also a key enabler to provide the ground for increased stakeholder understanding and acceptance of upcoming innovations & technologies at sea and create the interconnectivity between stakeholders.

As a driver towards more system, circular and life-cycle design thinking, MSP may allow future technologies to consider the full life-cycle including the re-use and re-purposing. Such examples are already now considered within the decommissioned oil and gas installations which after their initial lifetime may be re-purposed to serve other uses such as tourism (offshore hotel or a diving reef), hydrogen storage or carbon capture & storage. Current oil and gas installations are not designed with this re-purposing function in mind. Nevertheless, in the future, this may become a more relevant topic, especially in the planning scenarios which adopt the long-term perspective where the efficient use of space and long-term sustainability are the key aspects.

Although maritime spatial plans are normally designed to cover periods of up to 10 years, there is more and more understanding that MSP has to take an adaptive approach which keeps track with the technological progress and ensures that possible improvements and opportunities due to new technology, are not missed. Marine spatial plans today have to be designed as not to preclude future developments to take place.

Finally, MSP relies on improved data and especially information in order to enable good decision-making. Samples of such technology innovations are for instance the improved data sourcing on fishing activities (locations and fishing methods) provided by Vessel Monitoring System (VMS), Automatic Identification System (AIS), or even the Visible Infrared Imaging Radiometer Suite (VIIRS).

Other examples include the improvements in maritime transport data but also monitoring data. Big data-processing will make a big difference in MSP, also in connection with better assessment and decision making models & data processing software.

The MSP process itself has to make use of innovative governance solutions by using the latest technologies for MSP design and implementation.

SUSTAINABLE DEVELOPMENT

The 17 Sustainable Development Goals (SDGs), as defined in the 2030 Agenda for Sustainable Development, form the building blocks towards tackling climate change and preserving the oceans and forests. These SDGs are a challenge and an open call for technological efforts. The most obvious, when one thinks of ocean and seas, is of course SDG14 (Life below water). However, the ocean is connected to (sustainable) life at many more levels, which is also reflected in the wider set of SDGs to which the themes can be linked.

Desalination is closely linked to the SDG6 (Clean water and sanitation), but as it touches upon one of the basic needs for human life, namely drinking water, it is also intricately linked to SDG3 (Good health and well-being), SGD11 (Sustainable cities and communities), SDG2 (Zero hunger) and SDG14 (Life below water). **Coastal protection**, safeguarding the coastal zone and hinterland from flooding by infrastructural interventions, clearly touches on SDG9 (Industry, innovation and infrastructure), but also SDG14 (Life below water) and SDG15 (Life on land) and by preventing flooding and thus securing habitation in the densely built coastal zones, there are links with SDG1 (No poverty), SDG2 (Zero hunger), SDG11 (Sustainable cities and communities). **Clean shipping**, trough the use of alternative fuels, has an impact on SDG14 (Life below water), but also on SDG15 (Life on land) through better air quality and the required technological innovations are closely linked to SDG9 (industry, innovation and infrastructure).

Smart Seas and **Marine Spatial Planning** form a starting point and support for these realisations. On the one hand, they allow the use of technology to accelerate developments and, on the other hand, they provide a breeding ground for new development paths.

MSP is becoming an important tool to guide a public process. Moreover, it is a powerful instrument to put 'ocean space' on the sustainable development agenda and to catalyse innovation processes. Nevertheless, MSP will need to take also a more prominent role in facilitating the implementation of new technologies that contribute to SDGs.

NATURE-BASED SOLUTIONS FOR COASTAL PROTECTION

Human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels. It is generally accepted that global warming is likely to reach 1.5°C between 2030 and 2050 if it continues to increase at the current rate. As such, global warming already has a significant impact on a myriad of processes in our biosphere, and not in the least on the world's seas and ocean. In this context, the thermal expansion of seawater and the melting of land-based ice sheets and glaciers have resulted in an accelerated global mean sea level rise. It is expected that coastal systems and low-lying areas will increasingly experience adverse impacts such as submergence, coastal flooding, and coastal erosion due to relative sea level rise. Moreover, changes in the nature of storms, including their frequency and intensity, are expected to increase flooding risks and damages. Population growth, economic development, and urbanisation in these coastal regions will create additional exposures and risks for economic, social and ecological systems in the coming decades. Hence, without adaptation, hundreds of millions of people will be affected by coastal flooding and will be displaced due to land loss by the year 2100; the majority of those affected are situtated in East, Southeast, and South Asia.

Large, complex coastal protection schemes making use of highly technical, structural measures (e.g. surge barriers, dikes and levees, seawalls, etc.) have been constructed around the world. Recent consideration of the resilience of these systems has exposed vulnerabilities, including those related to sea level rise, larger and more frequent storms, and imbalances in local and regional natural processes (e.g. sediment processes, erosion). Increasing attention is being given to the role of natural coastal landscapes and features and local and regional processes to the resilience of coastal protection schemes and the long-term sustainability of these systems. Coastal protection schemes that carefully integrate natural systems, landscapes and processes as a part of the protection system will be more resilient and sustainable. Nature can provide engineering solutions: vegetation that

stabilises sediments and soil on shorelines, beaches, and dunes; mussel beds that mitigate the erosive effects of waves on shorelines; near-shore sediment processes that allow a beach to regenerate on its own following a coastal storm.

COASTAL PROTECTION SCHEMES THAT CAREFULLY INTEGRATE NATURAL SYSTEMS, LANDSCAPES AND PROCESSES ARE ESSENTIAL TO COME TO RESILIENT AND SUSTAINABLE SOLUTIONS.

Nature-based solutions refer to the use of natural systems and processes to provide a service that supports the engineering function of coastal protection measures or systems. Coastal protection systems can be described in terms of a spectrum ranging from systems composed entirely of engineered structural measures (e.g. dikes and seawalls) to entirely natural and nature-based (e.g. reefs, beaches, dunes). Between these two ends of the spectrum are the systems that combine, to greater or lesser degrees, the use of structural and nature-based solutions (e.g. a dike fronted by an engineered, constructed dune). In addition to valuable engineering functions related to reducing flood risks, nature-based solutions can also provide other social and environmental value, including habitat for species and recreation for communities.

Making 'common sense' use of nature-based solutions requires relevant knowledge of physical, geological, chemical, and ecological processes operating in natural systems. Investments in coordinated applied and fundamental research are needed to support the use of nature-based solutions to develop sustainable coastal protection systems. Open, broad collaboration between scientists and engineers in government, industry, and knowledge institutions can be used to accelerate building a common requisite knowledge base. It is important to recognise that both applied and fundamental research is needed and that developing long-term, high-quality monitoring data for structural and nature-based solutions and systems can provide future value in the form of more resilient and sustainable coastal protection systems and further ecosystem services. Technological innovations that support efficient and accurate data collection will be important to progress, e.g., use of autonomous drones for remote sensing, machine learning and AI to convert raw data into information and to support management and decision making.

From a policy perspective, advancing the use of nature-based solutions should be supported by developing a long-term vision for sustainable coastal protection and a strategy for developing confidence in the performance of nature-based solutions. Coastal protection systems must be developed using sound science and engineering practice. In order for systems to be sustainable, the long-term costs of operating and maintaining these systems must be understood and reduced. Nature-based solution pilot projects, at field scale, provide an important means for developing knowledge and the necessary technical capacity, at the organisational level, to implement nature-based solutions. Such pilots entail opportunities to develop, test and refine concepts; to "learn by doing"; and to address uncertainties and develop technical confidence and social acceptance for new approaches.

CONTINUOUS INVESTMENT IN APPLIED & FUNDAMENTAL RESEARCH AND MONITORING IS NEEDED TO UNLOCK THE POTENTIAL OF SUSTAINABLE NATURE-BASED COASTAL PROTECTION.

Nature-based solutions can also be thought of as nature-inspired solutions, meaning that the processes, elements and structures (i.e. landscape features) being used are from nature. The innovation necessary to advance and implement nature-based solutions should be guided by an overarching framework for establishing long-term goals for coastal systems and managing the risks and uncertainties associated with implementing new approaches. Paradoxically, policies and regulations that restrict the development of new or modified habitats and landscape features, i.e., nature-based solutions, can present obstacles to developing more sustainable coastal protection systems. Narrow interpretations of what nature is and the desire to return ecosystems to an arbitrary historical condition, that climate change will not allow, could limit opportunities to create future natural value. Nature-based solutions present an important opportunity to develop new policies to support and guide innovation that creates sustainable systems and future value for society and the environment. The role of technological innovation for nature-based solutions should be viewed in terms of using existing and new technology to understand, design and apply solutions that work with nature to create lasting added value.

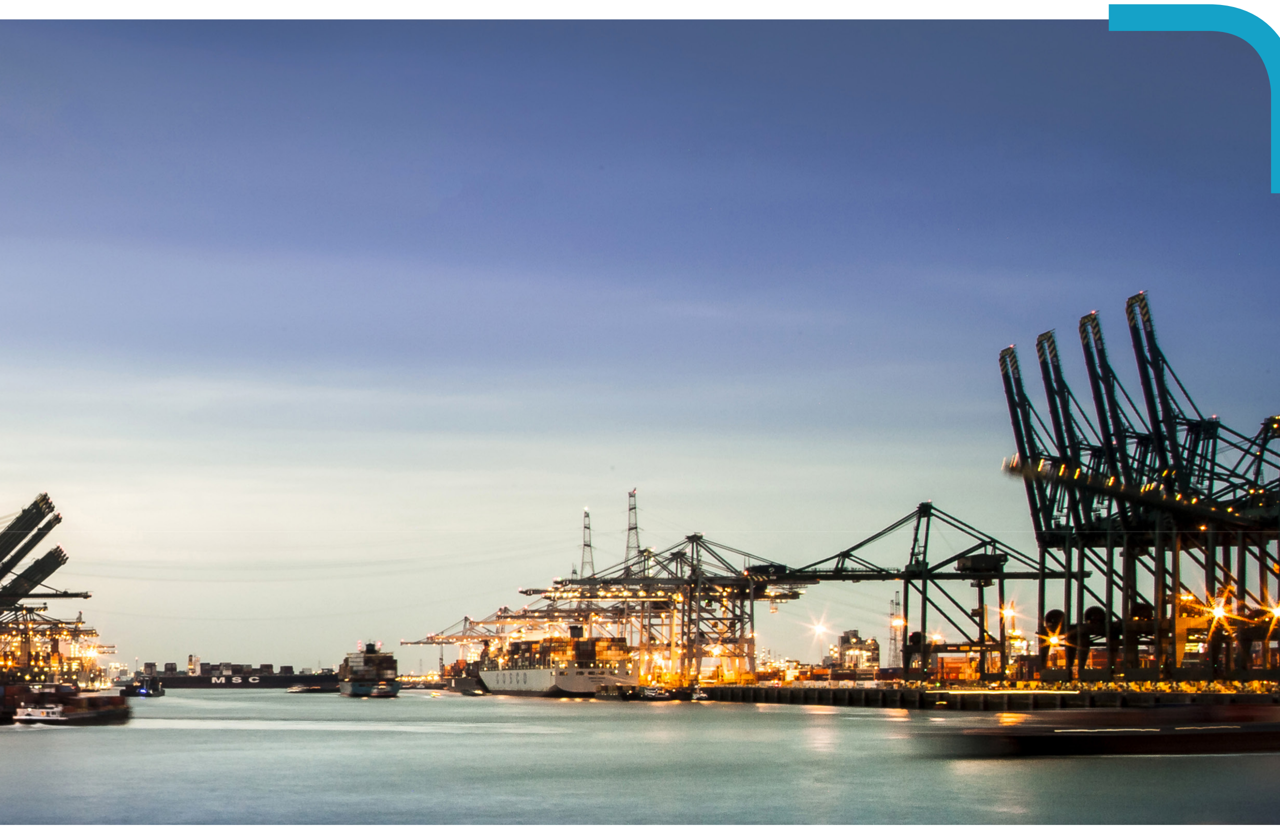
ALTERNATIVE FUELS TO MOVE TOWARDS CLEANER SHIPPING

Shipping activity contributes by as large as 2.5% of the total global greenhouse gas (GHG) emissions. They are generated over a wide range of operations during the ships voyage, e.g. while navigating in open sea or in restricted waters and when (un-) loading during port call. The actual share of global GHG, but also NOx/SOx emissions is expected to rise drastically considering current trends of economic growth, thus urgent measures are needed to reduce the negative impact of shipping on the environment. The Paris Agreement requires that a balance between emissions and removals of greenhouse gases needs to be achieved in the second half of this century. This demands urgent and ambitious action within the sector of international maritime transport. In the Brussels Declaration (2019) states, international organisations and the private sector are encouraged to invest and collaborate in research, development and deployment of innovative and effective technologies, zero emission fuels and any other relevant actions. The Declaration also encourages capacity-building and technical cooperation where needed.

To motivate the reduction of pollutants emissions the International Maritime Organization (IMO) has implemented an initial strategy on reduction of GHG emissions from ships. The current ambition trajectories, as defined by IMO, can be divided into 3 processes: reducing the carbon intensity of ships, reducing the CO_2 emission per transport work and reducing the annual GHG emissions by 50% by 2050 and phasing them out by the end of the century. Operational and technical measures are under development at the IMO to obtain these goals, i.a. through management plans to improve the ship's energy efficiency. Still, the IMO-goals are dependent on many factors, sometimes outside the control of the individual shipowners. The implementation of new technologies alone (low steaming, more energy-efficient hull designs, etc.) are, however, not enough to comply with IMO 2018 goals. A move towards the use of fuels with lower or zero carbon content is deemed necessary.

Low-carbon content fuels have been recently proposed as alternative to current marine fuels, for example: Liquified Natural Gas (LNG), Methanol (MeOH), synthetic fuels (GTL), Hydrotreated Vegetable Oil (HVO), etc. Other cleaner alternatives are zero carbon content fuels, for instance Hydrogen and Ammonia (from renewable sources) and batteries. However, the Technology Readiness Levels (TRL) of these fuels are in a very different stage of maturity.

Among fuels of the first type (low-carbon content), LNG has enjoyed a major acceptance. Other



technologies such as MeOH and GTL have also been implemented but on a lesser scale. While these fuels have a higher TRL and are more commonly used, they still face considerable challenges (e.g. the provision of adequate LNG-bunkering infrastructure) and the methane slip (unburned fraction), which is emitted while burning LNG. An alternative with a lower impact on the environment than LNG is methanol, as the MeOH slip has no global warming potential (unlike methane slip from LNG). Yet, methanol will require major investments or additional incentives to mature and to become economically viable.

A full switch to the second type of fuel (zero carbon fuels) faces even more limitations today because of their lower energy density. In addition, challenges regarding their insulation and volumetric space reduce cargo. In spite of these limitations, efforts have been made to include zero carbon fuels via different alternatives such as dual combustion (diesel-hydrogen) and the hybrid solution (diesel-electric). These solutions are, however, not yet zero compliant but reduce drastically the amount of pollutant emissions and are a step towards the full implementation of zero carbon content fuels in maritime transport.

Changing the entire fleet to complete zero emission can only be achieved by switching the current energy

sources and moving from internal combustion engines to fuel cells. From a technical point of view, new ships can be equipped towards zero emission, however from the operational and economical point of view, many hurdles are still to be taken.

For ships already in operation, an immediate solution must be sought to reduce pollutant emissions and reach IMO-goals. A solution to the pollutant emissions by current shipping can be found in transition fuels, such as GTL, MeOH, LNG, or dual technology (each one of them with a different contribution of emissions of pollutants). Still, the major limitations with respect to the use of these transition fuels is from the point of view of the ship itself, their lower energy density (implying larger volumes of fuel tanks needed or restricted vessel autonomy), the challenges of storing the fuel on-board, the associated safety issues, the limited bunkering supply, and ultimately their relative higher cost. From the shipowner's perspective, low-carbon fuels can only be used if the above problems are solved and if the necessary return on investment can be achieved. Investments are needed from both ports as ship owners, but a global level playing field and international regulatory framework needs to be in place to make these investments. Infrastructure investments are necessary to develop renewable energy provision for cold ironing (electric power supply shore to ship for (un)loading operations) and for a stable provision of alternative fuels (standardised connectors, fuel storage, etc.).

FROM A TECHNICAL POINT OF VIEW, NEW SHIPS CAN BE EQUIPPED TOWARDS ZERO EMISSION, HOWEVER, FROM THE OPERATIONAL AND ECONOMICAL POINT OF VIEW, MANY HURDLES ARE STILL TO BE TAKEN.

The amount and type of air pollutant emissions are obviously dependent on the used energy source.

Apart from this, it should be noted that when ships navigate towards a port, they usually do at restricted speeds (low and very low) and in confined waters (depth, width, etc.). The ships' behaviour under these conditions is obviously different compared to sea voyage where it navigates at full speed or at economical speed. When sailing at different speeds, the ship's emissions also differs. This is particularly the case when sailing at a speed lower than the engine's designed maximum efficiency. This raises questions regarding the actual burning of the fuel and the real amount of pollutants generated. For instance, when using LNG the NOx-formation exhibits significant differences when compared to the commonly used steady-state emission factors. Hence, the actual picture of pollutant emissions and their real potential to reduce harmful emissions by low or zero carbon content fuels might be blurred.

Even though establishing control areas such as ECAs (Emission Control Areas) is a proper response to SOx and NOx, they are not enough to reduce GHG -emissions. Restrictions of pollutant emissions should be global and not local. To reduce GHG-emissions, it is needed that regulations and incentives to use low-carbon content fuels are strengthened, while at the same time more investments should be done regarding research, innovation and the development of new low to zero carbon fuels, hybrid approaches, dual combustion, etc. The latter is crucial in order to build up next generation technologies that will allow zero carbon fuels uptake in the global market towards a shipping industry with zero emission.

SMART SEA AS A CONCEPT TO HARNESS SCIENTIFIC AND TECHNOLOGICAL PROGRESS

With 'smart seas' we understand 'harnessing scientific and technological progress to reconcile the need to use our ocean and its resources for food, energy, health, jobs, prosperity and wellbeing, with the necessity to safeguard and foster healthy, vibrant and productive ocean ecosystems.'

Science is crucial to achieving global sustainability and adequate stewardship of our ocean and seas. It provides the means to deepen our understanding of and monitor the ocean and its health, as well as to anticipate changes in its status. Moreover, it helps building the foundations for technologies that allow us to access and manage the ocean's resources. A fundamental basis for science are high quality, validated and sustained observations. To research long term trends of ocean variables, a proper record of reliable data needs to be accessible. Disregarding the importance of high-quality data, jeopardises future successful developments. Technology and technological innovations are an increasingly important pillar for the collection, validation and management of ocean data and considerable progress has already been achieved in recent years in the development and dissemination of such technologies.

Equally, over the next couple of decades, a string of key enabling technologies promises to stimulate yet further improvements in efficiency, productivity and cost structures in many ocean activities, from scientific research and ecosystem analysis to shipping, energy production, fisheries and tourism. Those technologies, if used well, have the potential to strengthen quite significantly our capacity to manage and govern our ocean and seas in a sustainable way. Examples for such smart seas-technologies range across a wide variety of disciplines and fields of application. They include for example subsea engineering, marine biotechnology, nanotechnology, advances in new materials and in chemistry, all of which find their way into a myriad of different ocean uses. Increasingly, the term 'smart seas' is employed more narrowly in the context of ICT and its many derivatives. Variations on those technologies comprise, among others, advances in imaging, physical sensors, satellites, big data analytics and autonomous systems. Digital innovations have been gaining ground quickly in almost all sectors of the wider economy. Artificial Intelligence (AI), cloud computing, robotics, 3-D printing, the Internet of Things (IoT): all have been spreading rapidly as they have been adopted by and integrated into a multitude of applications old and new. However, in many areas of the ocean economy their uptake has been markedly slower. Where they are being deployed, they are arousing considerable interest. Examples that come to mind are high-performance sensors & sensor-web-technologies and subsea imaging, autonomous offshore rigs, digital twinning in shipbuilding and marine equipment, AI in large-scale aquaculture and in offshore renewables.

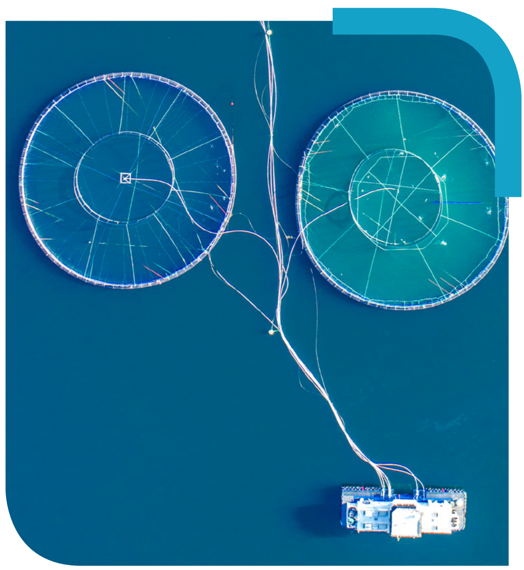
IN ORDER TO FULLY REALISE THE SMART SEA CONCEPT, A REDOUBLING OF EFFORTS IS NEEDED TO ENABLE TECHNOLOGY BREAKTHROUGHS AND TO CLOSE THE KNOWLEDGE GAPS.

One of the key solutions to implement the smart sea-concept is ensuring that the resulting data is accessible in a global open source context ('FAIR' concept, meaning Findable, Accesible, Interoperable and Reusable data). The ocean observing community is developing tools for making data accessible and processable to be able to interconnect machines to process the ever-increasing amount of available data. Hence, there are signs that the pace of digital innovation in the ocean is about to accelerate. In addition to the initiatives that arise internally within research and industry, from the pursuit of higher efficiency and further development, policy is also an important driver, as the requirements may be ahead of what technology can offer today. It is likely that the request for more efficient monitoring technologies will lead to further development of the smart sea-market in an oceanic context.

If the concept of 'smart seas' is to be realised, it will require a redoubling of efforts to create an environment truly propitious for marine and maritime innovation. That means encouraging innovation on both sides of the equation: helping achieve the breakthroughs that are required to exploit sustainably the rich opportunities that are now emerging for ocean industries, and encouraging the steps needed to address vital knowledge gaps about our ocean environment and its interaction with human activity, not least with a view to generating new effective tools for ocean governance and management. In order to better respond to marine and maritime activities that have the potential to affect the environment (such as, amongst others, noise, turbidity, salinity) a wide array of parameters needs to be monitored. However, it is necessary to choose what is important to follow up. With a pragmatic approach to prioritise certain variables, IOC is determining the Essential Ocean Variables through 2 criteria: firstly, the impact of the variable and secondly, the maturity of the sensor technology and the observance system.

In terms of the prospects specifically for digital technologies, the scope for progress is huge. There is room, among other things, for more learning from other non-ocean sectors and industries, for leveraging the benefits of smart innovation through the combination of technologies from different disciplines and specialities, and for laying the foundations for greater inter-connectivity of the increasingly sophisticated instrumentation, tools and platforms deployed in the ocean. That in turn presents a considerable challenge to all actors in the ocean economy to join forces and step up collaboration.

HUGE PROGRESS CAN BE ACHIEVED BY LEARNING FROM NON-OCEAN SECTORS AND INDUSTRIES.



Blue technologies for blue sustainability - Ocean and seas: challenges and sollutions

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