Maritime Sensor Technologies for the European Market: Research, Development and Implementation

Good practice guide

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This COLUMBUS guide was developed as a result of discussions with COLUMBUS and AtlantOS project partners, speakers and participants at the COLUMBUS Brokerage Events 'Knowledge Transfer in Maritime Sensing Technologies' on 23 November 2017 (AtlantOS General Assembly 2017, Gran Canaria) and on 23 January 2018 (EuroGOOS Headquarters, Brussels).

ABOUT THIS GUIDE

Over the course of successive EU Framework Programmes, the European Commission has made a significant investment in research and innovation projects designed to advance ocean observing and monitoring capacities through the development of marine environmental sensing technologies. There have been varying levels of transfer of intellectual property arising from these projects towards market/application and the reasons for this are both complex and varied. This guide considers some of the success stories as well as common challenges and bottlenecks along the value chain from research project to market/application and proposes, where possible, some recommendations.

The guide may be of interest to a wide audience but is particularly targeted at (i) funding agencies commissioning marine technology research and (ii) technology developers (private and academic) engaged in such research. Nevertheless, technology implementers and intermediaries will equally be interested in some of the recommendations and findings. The guide draws from and builds upon the work done across a number of complementary projects. These include the Horizon 2020 AtlantOS[1] project and the the Seventh Framework Programme Ocean of Tomorrow marine sensing projects, outputs from which are explicitly mentioned below.

The success stories, challenges and recommendations presented in this document are a compilation of views and feedback derived from dedicated events organized in the framework of the COLUMBUS project, focusing on knowledge transfer in research and development of innovative maritime sensing technologies. As a result, the views presented in this document may not necessarily be representative of the entire community and may even be challenged or contradicted by other stakeholders.

[1] https://www.atlantos-h2020.eu/

EXECUTIVE SUMMARY

The European Union's Seventh Research Framework Programme Ocean of Tomorrow initiative supported several cutting-edge research projects that made substantial and measurable progress in advancing a range of marine sensing technologies. However, the Ocean of Tomorrow vision to deliver a suite of new sensors which would be a commercial and operational success and support key policy and management objectives has not yet been fully realised. Ex-post assessment suggests that there is a disconnect between the ambitious goals set out in the original call texts, and what is actually achievable within the confines of a 3-4 year collaborative research project. Whilst some of these projects have been successful in commercialising products, demonstrating prototypes, and transferring innovative software to industry, the development of many promising technology leads has now stalled and may not be advanced any further because the project funding cycle has ended.

Marine environmental monitoring is a niche area with users spanning public bodies (e.g. responsible for national marine monitoring programmes), industry (e.g. oil and gas, offshore renewables, aquaculture, etc.) and researchers (e.g. oceanographers, climate change scientists, etc.). The market for marine sensors in Europe is not large. Some new technologies will be relatively easy to integrate into established marketable applications, replacing existing devices with cheaper, more efficient, more robust, longer lasting ones, once they have gone through the process of validation and demonstration of their performance to levels accepted by users. However, many of the new technologies under development across EU-funded technology projects do not have an existing or established market to enter.

The successful development and integration of new sensing technologies is a prerequisite for successful implementation of key EU policy goals such as achieving Good Environmental Status (GES) under the Marine Strategy Framework Directive. But these higher level policy goals do not necessarily create a market pull. There is an argument that for crucial policy goals such as achieving GES or implementing the UN Sustainable Development Goals, it may be necessary to use policy and regulation as a tool, possibly through setting specific technical standards, to boost demand for certain new marine sensing technologies. This may seem to be creating an artificial policy and regulation driven market and imposing costs on European countries. However, this should be considered in light of a broader question: in the long-term, which will be more expensive, effectively monitoring the marine environment or failing to monitor it properly?

Future calls in the area of marine technology/sensor development (in this case) should set out very clear and achievable expectations that allow for realistic proposals, and discourage the kind of over-reach on behalf of the proposers which is common and increasingly necessary in a highly competitive R&D environment. Equally important is to ensure that the 'need' or 'demand' according to which the call was launched is real and has been identified in collaboration with the proposed end-users/implementers of the new technology.

Co-creation and co-development of research should be a pre-requisite, ensuring that the ultimate potential users of the technology are involved in the design of the projects from the outset. The employment of a panel of independent expert project monitors, including end-users, at evaluation stage and throughout the project helps to ensure that the appropriate consortium is funded and achieves what it proposes.

Despite efforts in communication and knowledge transfer, it is clear that a key barrier to bringing forward or exploiting pre-commercial intellectual property developed through EU-funded research is the lack of exposure to 'next users'. There is a case to establish an actively managed virtual market place, where such intellectual property is clearly described, documented (technology, application, TRL level, intellectual property protection, etc.) and where users in both the private and public sector can monitor new technologies and, if interested, engage with the intellectual property owner. This could be progressed through a targeted and pro-active European maritime technology transfer function, providing tailored tech-transfer support to technology developers (with dedicated funding options) enhancing knowledge transfer and commercialisation.

Research and development in the field of maritime sensing technologies in Europe represents significant potential for further growth in this sector. For this potential to be realized however, it is important to ensure that the significant EU research and development investment (both at EU and national level) is targeted at the right areas and focused on addressing real-life marine monitoring challenges and opportunities. Moreover, new intellectual property (IP) generated should be taken up to drive towards competitive and marketable sensor technologies and products and realise Europe's full potential as global leader in sensor technology research and development.

EUROPE'S MARITIME SENSOR TECHNOLOGIES SECTOR: STATE OF PLAY AND FUTURE OPPORTUNITIES

WHERE WE ARE

From 2010-2013 the European Commission invested €195.6 million across 32 projects under the Seventh Framework Programme (FP7) "Ocean of Tomorrow"[2] call. The call was designed to deliver some of the knowledge needs identified in the European Strategy for Marine and Maritime Research (COM (2008) 534) and to address marine science and technology challenges that cut across the ten established thematic priority areas within the FP7 Cooperation sub-programme. In addition, Ocean of Tomorrow fostered multidisciplinary approaches and cross-fertilisation between various scientific disciplines and economic sectors on key cross-cutting marine and maritime challenges.

The Ocean of Tomorrow 2013 third cross-thematic call focused on the development of innovative maritime technologies for a range of applications, with one of the three key focus areas being marine sensing technologies[3]. Nine projects were funded to develop marine sensors representing an investment of just under 50Million euro (detailed in Table 1 in Annex). These were grouped into two topics, with five projects funded under topic 1 'OCEAN 2013.1 – Biosensors for real time monitoring of biohazard and man-made chemical contaminants in the marine environment' and four funded under topic 2 'OCEAN 2013.2-Innovative multifunctional sensors for in-situ monitoring of marine environment and related maritime activities'. Both topics highlighted the following requirement 'the multi-sectoral composition of the partnership and the participation of industrial partners and relevant end-users, in particular SMEs, are essential for the implementation of the project' and noted that projects would be evaluated on this under the 'implementation' criterion. Topic 1 stated that projects should 'include a test phase to demonstrate the potential of these biosensor(s)...' and that 'a proof of concept in terms of product and/or process should be delivered within the project demonstrating industrial manufacturability.' Topic 2 went further and included the following requirement 'An essential part of this topic will be to ensure technology transfer through an integrated approach, bridging between laboratory testing and commercially viable product.'

These application-orientated projects as well as the inclusion of SME and in some cases industrial partners aimed to put Europe at the forefront of marine sensing technology development and to facilitate the further exploitation of these technologies. Table 1 reviews the outputs of these projects and it is clear that significant progress has been made in the development of innovative in situ marine monitoring technologies.

[2] The ocean of tomorrow projects (2010-2013) Joint research forces to meet challenges in ocean management. Published: 2014-03-13 Corporate author(s): Directorate-General for Research and Innovation (European Commission) https://publications.europa.eu/en/publication-detail/-/publication/85b05ee8-7f0b-49ae-80ba-0bbb811de915/language-en

[3] https://ec.europa.eu/research/participants/portal/desktop/en/opportunities/fp7/calls/fp7-ocean-2013.html

In addition to the focus on new instrumentation, these projects, in particular those funded under Topic 2, also made significant advances in data management and standardisation[4] (especially considering European directives such as INSPIRE[5] intended to strengthen interoperable sharing), contributing to Europe's role as a global leader in data interoperability. These outputs and specific recommendations on how they can be further exploited are extensively reviewed in a policy brief[6] produced by the SenseOCEAN project, in collaboration with the three co-related Topic 2 projects, NeXOS, Common Sense, and SCHeMA[7].

Beyond this cohort of projects, the Horizon 2020 AtlantOS project has produced 'Sensors and Instrumentation Roadmap[8]' a ten-year 'open access technology roadmap for research centred in and around the Atlantic Ocean to both engage and improve collaboration and integrated effort from all stakeholders.' It is intended to update this document periodically throughout the AtlantOS project.

Significant progress has been made by the Ocean of Tomorrow projects to advance European capacity in innovative maritime sensing technologies, data collection, management and sharing. The SenseOCEAN project has already delivered several new products to the market[9]. Despite these successes, COLUMBUS Brokerage Events[10] have highlighted that there are little or no opportunities to maximize the uptake and further exploitation of those projects, now that the funding cycle has ended. The reasons for this are considered in the next sections.

" Are we delivering value in return for the EU investment in marine sensor and observing technology research?"

OPPORTUNITIES FOR EUROPE

Europe can benefit in many ways from the development of new marine sensors and sensor technologies.

Research: advances in sensor technology can promote greater capabilities and efficiencies in marine and climate research, advancing our understanding of marine environmental processes and the impacts of climate change. Research has been shown to be one of the main drivers of market growth in this area[11].

Policy, Management and Public Engagement: developing robust, low-cost, long-life ocean sensing and observing technologies is key to

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[4] Oceans of Tomorrow Sensor Interoperability for In-Situ Ocean Monitoring. Pearlman *et al* 2017, OCEANS Conference, Aberdeen http://ieeexplore.ieee.org/document/7761404/

[5] https://inspire.ec.europa.eu

[6] Policy Document: Sensor development for the Ocean of Tomorrow http://www.senseocean.eu/senseocean/sites/senseocean/files/documents/Deliverable%20D7.8%20Policy%20Document%20Sensor%20Development%20for%20the%20Ocean%20of%20Tomorrow_r.pdf

[7] Four projects funded under the OCEAN-2013.2 call: COMMON SENSE – Cost-effective sensors, interoperable with international existing ocean observing systems, to meet EU policies requirements; NeXOS – Next generation, cost effective, compact, multifunctional web enabled ocean sensor systems empowering marine, maritime and fisheries management; SCHeMA – Integrated in situ chemical mapping probes and SenseOCEAN – Marine sensors for the 21st Century.

[8] https://www.atlantos-2020.eu/download/deliverables/6.1%20Sensors%20and%20Instrumentation%20Roadmap.pdf

[9] http://www.senseocean.eu/news

[10] COLUMBUS Brokerage Events 'Knowledge Transfer in Maritime Sensing Technologies' on 23 November 2017 (AltantOS General Assembly, Gran Canaria) and on 23 January 2018 (EuroGOOS Headquarters, Brussels)

[11] http://www.nexosproject.eu/sites/default/files/NXS_WP2_D2.1_v.2.1_Market_%20assessment%20and%20competitiveness.pdf

[12] https://ec.europa.eu/maritimeaffairs/sites/maritimeaffairs/files/swd-2017-128_en.pdf

enabling sustainable management of maritime activities and supporting Blue Growth[12]. It is also crucial for delivering important EU policy objectives towards achieving Good Environmental Status under the Marine Strategy Framework Directive[13]. Increasingly attention is turning to citizens' observatories[14] as a low-cost, large-scale complement to in situ monitoring. Novel sensor technologies can ensure the reliability and standardisation of data collected using these methods. Supported community engagement increases the public's awareness of environmental risks and has a positive impact on policy and governance.

Business and jobs: there are significant opportunities for technology developers to deliver marketable solutions which drive new business opportunities and create jobs both in Europe and globally. This is also an area that will engage young professionals. The following summarises some key points from an in-depth analysis of the European sensor market, produced in the framework of the NeXOS project[15].

Europe is a global leader in sensor technology and development. European sensor manufacturers are usually SMEs, for whom marine sensing technology development forms a significant part of their activities. This contrasts with the North American market where fewer larger companies control the market. Due to regulatory issues, it is very difficult for EU companies to break into the North American market. These smaller EU companies also face competition from North American companies at home, with the latter being recognised brands and often the preferred supplier in Europe. A study[16] considered patents and scientific publications as markers for assessing a country's position in leading technological development in an area (in this instance environmental monitoring), and thus indicative of its potential competitiveness. Whilst the US leads in terms of the number of patents (reflective of the larger market players as compared to European SMEs who are often reluctant to file patents for reasons outlined below), the EU leads in terms of scientific publications. Since these can be seen as indicators of future innovations they reinforce the strength of European research and development in marine sensing technologies as a breeding ground for future growth in this sector.

For this potential to be realized, significant EU research and development investment (both at EU and national level) should be targeted at the right areas. It should be focused on addressing real-life marine monitoring challenges and opportunities and ensure that new intellectual property (IP) is taken up to drive towards competitive and marketable sensor technologies and products.

[13] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0056
[14] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4320485/
[15] http://www.nexosproject.eu/sites/default/files/NXS_WP2_D2.1_v.2.1_Market_%20assessment%20and%20competitiveness.pdf
[16] Ecorys, Deltares and Oceanic Développement (2012), 'Blue growth: scenarios and drivers for sustainable growth from the Oceans, Seas and Coasts'_ Maritime sub-function profile report environmental monitoring (6.3)https://webgate.ec.europa.eu/maritimeforum/en/node/2946

BARRIERS TO REACHING THE MARKET

COLUMBUS Brokerage Events discussions[10] with researchers and SME representatives have identified specific challenges and barriers impeding the transfer of intellectual property generated in research projects and Technology Readiness Levels (TRL) progress towards marketability. These fall within a range of categories outlined below.

The biggest barriers are illustrated by elaborating a set of statements voiced by technology SMEs, researchers and actors in the ocean monitoring and observation community. Whilst they are grouped within categories, some of the barriers will be cross-cutting or potentially applicable beyond the marine and maritime realms. The maritime sensing technology market in Europe faces one specific over-arching challenge: the adaptations required for these technologies to operate in the harsh marine environment represent significant costs, whilst also limiting the potential market in some instances.

FINANCIAL BARRIERS

“There are sufficient financing tools available to support initial R&D but it is very difficult for companies to bring the sensor technology from TRL 5/6 towards TRLs 8+ and the market.”

- With R&D funding typically received via research projects, technology is developed to about TRL 5/6, to the stage of prototype development. The question is how to move to demonstration, i.e. to TRL8? This is ‘the innovation valley of death’ for technology developers. It is particularly difficult for SMEs working on marine sensing technologies to find external funding for later stage developments because investors are less familiar with the market opportunities and may perceive a higher risk. The hostile conditions of the marine environment and its relative inaccessibility also means that testing marine sensing technologies is much more expensive than testing on land and dedicated marine test infrastructures are often required.

“ Often the market is not aware that these innovative sensors have been developed.”

- Many research projects focus on design and development but not so much on marketing. In many cases, stakeholders or potential technology implementers are not involved in the initial development process which means they have to be engaged at a later stage. This requires significant additional resources on the part of the SME or IP holder to convey the basic information, specifications and potential of the technology.

  Where potential customers are the research community, the SME developing the technology has to publish in peer-reviewed journals to create a ground-swell of demand. This can be a challenge for the SME. The communication gap is further enhanced by the fact that the research community tends to prefer scientific conferences to trade shows.

“ Projects are relatively short-term.”

- The time taken to develop a commercial product, considering the research, development, demonstration and business phases often extends beyond the typical three-four year time scales of research and innovation projects.

“ The market for ocean sensors is not large enough.”

- The ocean sensors market is small, conservative and controlled by relatively few players. It is not large enough or not sufficiently well known to attract venture capital funding.

“ Consideration must be given to minimising operational expenditure (OPEX) costs for innovative technologies.”

- Minimising the operational cost of installing, maintaining and recovering or replacing sensors is often not taken into account in the development of sensors and this can limit their take-up.

CULTURAL BARRIERS

“ Target users may be unwilling or unable to trial the new technology.”

- There is a recognised need to develop innovative sensors that reduce time and costs of marine observation and monitoring activities. However, there is often an unwillingness by public bodies to change the status-quo and adopt innovative approaches and new sensor technologies - even if these could potentially reduce investments in time and costs. Reasons for this can include reluctance to implement changes that could result in breaks in unique long-time series measurements or a lack of confidence in the robustness of new sensors, which are not yet well documented or sufficiently calibrated in real working environments. This can be frustrating for intellectual property owners/developers who know that their innovative technology can advance the state-of-the-art and reduce costs or time – if it were given a trial period for demonstration and validation. Likewise, developers are often not familiar enough with the procedures and regulations governing environmental monitoring programmes, which hampers the uptake and implementation.

“A lack of effective communication within the project can impede the speed of development of the technologies.”

- This is particularly the case when developing innovative technologies requiring collaboration between different disciplinary backgrounds. Significant time can be lost in understanding what is required in order to adapt a platform to incorporate a new sensing technique, for example.

“There is a demand for end-to-end solutions.”

- Creating specified end-to-end solutions can be difficult for an SME, considering the costs involved in tailoring their innovations to specific requirements.

“A societal need does not equal a market.”

- It is well recognized that there is a need for innovative sensors to assess the ocean health, in line with the Marine Strategy Framework Directive (MSFD) and Sustainable Development Goals (SDGs), both of which are often referred to in R&D funding calls. However, often the market is not mature or large enough to pull the technology through from prototype to commercialization after the project ends.

REGULATORY BARRIERS

“For young SMEs there are costs and risks associated to patent application.”

- For this reason young SMEs often prefer to use ‘know-how’ over ‘patent’ to protect their intellectual property. This also minimises the risk that their innovations could be taken over by a stronger player.

“Differing motivations creating differing approaches to patenting between academic and industrial researchers in a collaborative project.”

- Academic researchers, under pressure to publish, file patents early. In industrial research, patents are often filed as late as possible to ensure that the market is there before incurring the costs associated to patent filing.

“Sometimes it is not clear who owns the intellectual property in a large multi-partner project.”

- Research projects do not always result in the expected outcome. Sometimes what is attained has not been expected and it is not clear who owns the intellectual property on what has been developed, or how it could then be further exploited.

> **" Incorporation of new technology into long-term marine monitoring programmes can be very slow."**

- Current marine monitoring programmes tend to be reactive and not proactive; in the case of harmful algal blooms these can result in significant losses both for fish farmers and tourism. Changing the status-quo is not something that can be achieved by a technology developer. Introduction of new technologies into ongoing monitoring programmes requires validation of the new technology and side-by-side comparison against the old system to allow calibration. In some instances, where for example innovations allow testing of the water for pathogens as opposed to post-mortem testing of animals, there is no equivalent test and so validation can be extremely difficult.

  Integration of a new technology can also require changes in sampling methodology, data analysis and interpretation of the data to meet policy requirements[18]. These can be costly and time-consuming and unless required to do so, it is unlikely that public bodies will integrate new technologies of their own initiative. Whose role is it to ensure that public monitoring bodies adapt to utilise new cost-effective technologies?

TECHNICAL BARRIERS

It is not the purpose of this report to consider in detail the technical challenges faced by marine sensor developers. These challenges have been the focus of many studies in the framework of national, regional and European projects. A recent study carried out by the FP7 NeXOS project to assess the current market for marine environmental sensors and the competitiveness of European sensor manufacturers[19] identified several technical challenges common to all sensor market sectors; their findings are briefly described below. Common to all will be the demands of operating in the harsh marine environment for long periods of time, far from shore.

Power requirements: the need for adequate power supply for operation of sensors and data transmission from sensors which are often working in remote conditions for long periods without the possibility to recharge easily.

Sensor stability: this category includes both 'reliability', meaning that external physical conditions do not impinge on the accuracy of the data measurements and 'robustness' referring to the ability of the sensor to withstand extreme physical conditions in which they must operate (pressure, temperature, current). Although listed as a separate technical challenge in the NeXOS report, this 'robustness' could also include biofouling which can also impede the proper functioning of a sensor.

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[18] https://www.frontiersin.org/articles/10.3389/fmars.2017.00263/full

[19] http://www.nexosproject.eu/sites/default/files/NXS_WP2_D2.1_v.2.1_Market_%20assessment%20and%20competitiveness.pdf

Standardisation: sensors are seldom used in isolation and are usually deployed on mutli-sensor platforms. Integrating independently-manufactured sensors is costly and time-consuming and yet, it is difficult for manufacturers to provide off-the-shelf sensors as clients, particularly from the oceanographic community, often require specialized sensors.

Interoperability: this is closely linked to the above standardization challenges. Software must be developed for the specific platform and sensor array. This software is not usually interchangeable between different platforms and sensor arrays. Achieving standardization of data and metadata formats as well as relevant interfaces could lead to significant cost reduction, especially if domain-independent standards are followed which ensure interoperability between different thematic domains. This would also strengthen the re-use of collected data in contexts that were originally not foreseen.

Data transmission: some sensors are deployed to collect data for long periods of time far from shore. In such cases, data is transmitted by satellite at high costs. For this reason often only a portion of the data is transmitted, with the remainder stored and downloaded when the sensor is back on shore or recharging at a docking station. This impacts on the quantity of real-time data that is available for the user.

In addition to these general challenges, it is important to note that the operational use of autonomous biogeochemistry and biology sensors remains in its infancy.

RESEARCH PROJECT DESIGN

" In some instances the intention of the project is to advance the scientific state-of-the art."

- This may not result in a technology with a high TRL, and therefore make it very difficult to progress after the funding cycle ends. However, it may represent a step-change in sensing technology development. Therefore, a low TRL is not necessarily indicative of failure to progress. It is important that this is recognised and further advanced but it is not always clear how this can be achieved.

" A viable and mature market for the technology may not yet exist."

- Research project evaluation demands that projects contribute to addressing grand societal challenges and demonstrate impact. In this context, many recent research projects have been positioned to develop technologies to detect new parameters relevant to these grand challenges e.g. microplastics pollution or climate change. However, the market required to pull the technologies through to TRL 8 may not be mature or even exist at all. Whilst the call to which the project responded recognized the need to monitor emerging pollutants, for example, who is responsible for effecting the change in public monitoring that will create the demand for these new technologies and help advance them beyond TRL5/6?

“ Projects have grown too large and too collaborative.”

- The need to create large, representative consortium, including leading researchers, institutes and businesses can lead to projects that are very difficult to implement and carry dead weight resulting in inefficiencies. These also create difficulties in managing and protecting intellectual property. In some cases, researchers, as well as SMEs, prefer to go to smaller and more lean national funding programmes to protect their intellectual property.

“ Promised impact versus achievable impact.”

- Research and innovation funding is extremely competitive and in the marine sensing domain increasingly applied. Often the desired impact is not feasible. Projects, such as those funded under Ocean of Tomorrow, are expected to do basic research, technological-development, demonstration, and develop business-plans within the course of a 3-4 year project. Unless there are already established relationships with market players in a consortium, this is largely unfeasible.

  Researchers are asked for and promise the earth in order to get funded. Whose role is it to manage expectations and ensure that only projects that are designed to achieve their impacts get funded?

RECOMMENDATIONS

Below we present possible solutions proposed to circumvent or overcome generic challenges and barriers as identified earlier in this guide. They are based on input from various experts and in some instances they may be contradictory. This reveals a lack of consensus on how to tackle some of these issues and highlights the need for further discussions between funders, developers and implementers.

FINANCE AND FUNDING

- There is a need to separate the phases of the value chain with appropriate funding models, between R&D and business development. It is necessary to consider what is achievable in the first phase and ensure that promising outputs are fully documented and presented in a way that can be taken forward post-project by interested businesses.

- Funding agencies need to consider open lines of grant-aid and venture capital for technology developers throughout the value chain. This will help projects delivering valuable intellectual property (IP) receive rapid access to new funding streams to ensure the IP is taken forward. A coherent and connected research and commercialization system can maximize the potential for success for technology developers in negotiating the valley of death.

- Because the ocean sensor market does not attract venture capital, there is a need for a mechanism for risk-sharing with SMEs. One way could be to promote government-industry partnerships where the government also shares the rewards of success. Wider application of government supported venture capital fund to support maritime technology developments should also be considered.

- There is a need for more pre-call market analysis to ensure new technology is useful for industry. This is particularly important if the intention of the funding call is to contribute to economic value creation. This will help to evaluate market opportunities and to identify additional measures required to ensure sufficient market pull.

- Pre-commercial procurement is an interesting model to consider. This involves the potential user (e.g. private sector or public body) publishing their need or challenge and inviting interested parties to bid for the opportunity to address it. This can follow a phased process, with a number of applications competing in Phase 1 and the most promising proceeding to Phase 2 and so on. This ensures that the end-user defines the need and contributes to the monitoring of the projects.

- There are significant benefits from market requirements "consolidation". That is the ability to have common specifications to effectively enlarge the size of the market for a sensor. This could come from standards, but more likely from government encouragement of the research community and collaborations with large private sector players.

- A tool to help SMEs move to the next funding stage would be very valuable, or a much clearer/more visible funding system where successful R&D projects are supported by follow-on funding opportunities (either R&D funding or enterprise and commercialization funding).

- Research infrastructures can play a crucial role in supporting technology developers to bridge the valley of death and advance TRL from 5 to 8.

- A comprehensive cost-based (CAPEX and OPEX) review/stock-taking of the sensor technology developed in FP7 and H2020 would generate valuable information that could be used to inform the development of future sensors technologies, but also the allocation of future funding.

- EU and national funders can help technology to move forward by establishing new application projects to be more responsive to market needs. This step would be necessary to increase the TRL of developed products from 7 to 9. Regulations can be put in place to facilitate the establishment of markets.

- Advancing from TRL7-9 represents a particular challenge for marine technologies given the inaccessible and harsh marine environments in which prototypes must be tested, and the additional associated costs this necessitates.

- Exemplar projects that achieved their promised impact, within the project timeframe, should be analysed and their approach highlighted as best practice. One such example is the SenseOCEAN project, which resulted in the commercialization of new sensors within the lifetime of the project. Of interest in this example is that SenseOCEAN was coordinated by an institute with a dedicated marine technology transfer unit and a history of strong relationships with the relevant industrial sectors.

CULTURE AND COMMUNICATION

- Communication at all stages of development is key. Often this is required between quite different sectors and communities, for example molecular biologists and hardware engineers. Lack of effective communication can slow down development, with one party or another not fully understanding the vision or what is expected from them.

- It is essential to allocate sufficient attention to internal and external communication and dialogue – critical to ensure smooth development and address any skepticism or silo thinking by funders and implementers.

- There is a need to open the dialogue between customers, SMEs, policy-makers, funding agencies, investors and public/private researchers to improve knowledge transfer, ensure that it is user-driven, and that funding calls reflect actual needs.

- Developers need to be aware of the often complex legal and regulatory environment within which the technology they are developing may ultimately be implemented. Dialogue and interaction with environmental managers and policy advisors/makers from early on is a pre-requisite for success. Ideally, these connections should be made during a research project proposal preparation.

- Early involvement of policy and legal advisors or monitoring programme managers may help to guide the development path for a smooth integration of a new technology or sensor into routine monitoring/observing activities. It will also allow influencing the development from early on to ensure the technology is fit for purpose. There should be an awareness of legislation around the area in which the sensor will be applied.

- Visibility of promising research outputs should be increased via a curated catalogue or platform of technologies, products and procedures as well as IP status. Ideally, such a platform should be actively managed to target users. A passive approach relying on potential users finding and trawling through a database compilation of outputs is unrealistic. Demonstration of the most promising results in a living lab, facilitating the use in future projects, would also be very beneficial.

- It is important to communicate what has not worked and why; this is not necessarily a failure of the project and can ensure that other projects do not make the same mistakes.

LEGISLATIVE AND REGULATORY

- Give access to legal advice on intellectual property management, in particular for SMEs in collaborative projects, if this is inhibiting advancement of technologies developed within projects.

- For a project to deliver a technology that will be implemented in a monitoring programme requires buy-in from public monitoring bodies. They should be willing to trial or adopt new technologies that have been developed with public money, e.g. for the EU Marine Strategy Framework Directive implementation. This buy-in can create the market pull needed to advance innovative sensors from low to high TRL levels.

- The project funded to develop new sensors for marine monitoring must ensure that the appropriate actors who have influence in these spheres are involved in the project design and implementation. This also requires expert knowledge at the project evaluation stage to ensure that only projects with a realistic and achievable knowledge transfer pathway are funded.

TECHNICAL

There would be many and varied recommendations relevant to overcoming technical barriers and these were not the focus of this activity. Some recommendations arising during the brokerage events discussions are below.

- Sensors must be developed to consider data provenance and end-to-end data flow from sensors to users. This should especially comprise interoperable data and metadata formats as well as interfaces that cover the whole path from the sensor into the end-user application.

- Sensors must have sustainable high-quality manufacturing and stability in production backed up by strong customer service and training. Consider what has been done for CTDs[20].

- Sensor technology is also about the software – for transmitting integrating and sharing the data. Best practices[21/22] and recommendation guides already exist for common methodologies and protocols towards harmonisation of equipment (e.g. JERICO[23]), that could help in the standardization and interoperability of sensors (especially considering Sensor Web Enablement standards). Europe is at the cutting edge in this field and NeXOS, SenseOcean, Schema and CommonSense projects have shown this. E.g. NeXOS were able to demonstrate knowledge transfer of their open source software to a large company and this is repeatable. The SenseOCEAN[24] policy brief prepared in collaboration with their Topic 2 sister projects also deserves significant promotion.

- Sensor data flows developed in projects should be aligned to relevant European directives and frameworks such as the INSPIRE directive which aims at an interoperable sharing of geospatial data sets, also including observation data.

[20] CTD stands for conductivity, temperature, and depth, and refers to a package of electronic instruments that measure these properties.
[21] QUASIMEME (Quality Assurance of Information for Marine Environmental Monitoring in Europe) http://www.quasimeme.org/about
[22] https://www.oceanbestpractices.net/
[23] http://www.jerico-ri.eu/

RESEARCH PROJECT DESIGN

- Project design should be more strategic and objectives to achieve impact should be SMART and resourced accordingly.

- All project proposals should include a detailed Knowledge Management Plan. The Knowledge Management Plan should demonstrate what will be developed and how it will/could be applied/advanced after the project is completed, including a concrete description of how far it will advance along the value chain in the life of the project.

- Knowledge transfer needs to be at the microscale not the macroscale. Often the end-user identified by a project is further down a chain of intermediate users and this should be considered. Project promoters should ask themselves – at what stage of 'usability' will their technology be at the end of the project and what/who is best placed to use/test it or bring it to the next level.

- There is a need for much more effective project evaluation and close project monitoring during the project duration as well as post-project stock-taking by experts, to establish what IP has been developed and to advise on the next steps in knowledge transfer and commercialisation. However, all of these would require additional effort from the research funder.

- Projects that hope to bring a product to market must be co-designed with industry from their inception to commercial scale development. Involvement of industry from day one can prevent duplications of effort and also mean that developments are market-orientated and address real-life challenges.

- End-user feedback is crucial and potential end-users of the technology should be consulted from the onset to ensure the technology is fit-for-purpose. Funding agencies commissioning marine technology research should make this a requirement of the funding award.

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[24] Policy Document: Sensor development for the Ocean of Tomorrow
http://www.senseocean.eu/senseocean/sites/senseocean/files/documents/Deliverable%20D7.8%20Policy%20Document%20Sensor%20Development%20for%20the%20Ocean%20of%20Tomorrow_r.pdf

CONCLUSION – MOVING FROM PROMISE TO REALITY

Europe has a long history at the forefront of innovative maritime technology developments and is a global leader in sensor technologies.

Expectations are high for new and innovative marine sensor technologies to help address important societal needs in a more far reaching and cost-effective way. Significant progress has been made over the last few years, amongst others, in the scope of a range of EU projects funded by the FP7 Ocean of Tomorrow initiative. However, breakthrough in this area has been hampered by different bottlenecks along the value chain.

A concerted effort is needed to create a supportive environment to stimulate progress along the maritime sensing technology value chain, from identification of requirements to research and development, and up to full market uptake and application by end-users. Advances in sensor technology will help strengthen our research capacity, increase the confidence in scientific outputs and improve our understanding of marine environmental processes and the impacts of climate change. Robust, low cost, long-life ocean sensing and observing technologies will also improve our capacity to sustainably manage maritime activities. This is crucial for delivering important EU policy objectives, e.g. progress towards Good Environmental Status under the Marine Strategy Framework Directive. Creating the right environment allowing new sensing technologies to be developed and brought to market will have a strong impact on Blue Growth, delivering marketable solutions, reducing costs for maritime industries and driving new business opportunities. In addition the development of innovative maritime sensing technologies is a crucial step to achieve the Industry 4.0-transition in the offshore domain.

To realize this vision and deliver impact and value in terms of return on investments, there are significant hurdles to overcome, many of which are outlined in this document. All actors and stakeholders (funders, developers, implementers and end-users) will need to work together and take action to address challenges identified at the research design, technical, financing, cultural and legislative/regulatory level. There are also a number of actions that require buy-in from across the value chain, in particular the breaking of cultural and language barriers between the various communities and disciplines.

The following three aspects are likely to have the greatest possible impact and should be considered for priority action.

FUNDING CALL AND PROJECT DESIGN – KNOWLEDGE MANAGEMENT AND EXPECTED IMPACT

Future calls in the area of marine technology/ sensor development (in this case) should set out very **clear and achievable expectations** that allow for realistic proposals, and discourage the kind of over-reach on behalf of the proposers which is common and increasingly necessary in a highly competitive environment. Equally important is to ensure that the 'need' or 'demand' according to which the call was launched is real and has been **identified in collaboration with the proposed end-users/ implementers** of the new technology.

Co-creation and co-development of research should be a pre-requisite, ensuring that the ultimate potential user(s) of the technology are involved from the very outset in the design of the projects. Project impact should be evaluated on the basis of a detailed knowledge management plan, outlining clearly what knowledge outputs are expected, by when, for whom and how the knowledge will be transferred. **Users should be clearly identified, included and evaluated** - this is key to the success or otherwise of a project.

A panel of independent external expert project monitors, including end-users, at evaluation stage and throughout the project will help ensure that the appropriate consortium is funded and achieves what it proposes. The COLUMBUS project's **knowledge transfer** methodology, places significant importance on identifying the **appropriate target user at each stage of the value chain** to ensure that knowledge outputs can eventually reach and be used by the identified user.

A VIRTUAL MARKET PLACE FOR ADVANCED MARINE TECHNOLOGY INTELLECTUAL PROPERTY

A key barrier to bringing forward or exploiting pre-commercial intellectual property developed through EU-funded research is the **lack of exposure to 'next users'**. There is a case to establish a virtual market place, where such intellectual property is clearly described, documented (technology, application, TRL level, intellectual property protection, etc.) and where users in both the private and public sector can monitor new technologies and, if interested, engage with the intellectual property owner. This must be actively managed to achieve maximum results and could be progressed through a **targeted European maritime technology transfer** providing tailored tech-transfer support to technology developers, enhancing knowledge transfer and commercialisation.

BOOSTING THE MARKET THROUGH POLICY AND REGULATION

Marine environmental monitoring is a niche area with users spanning public bodies (e.g. responsible for national marine monitoring programmes), industry (e.g. oil and gas, offshore renewables, aquaculture, etc.) and researchers (e.g. oceanographers, climate change scientists etc.). Some new technologies will be easy to integrate into established marketable applications, replacing existing devices with cheaper, more efficient, more robust, longer lasting ones. However, **many of the new technologies do not have an existing or established market**. The technology might target a parameter that was not previously measurable and hence is not part of established monitoring programmes. Alternatively, it may present a completely new basis for measuring a standard variable, but where a benefit may accrue to adopting the new technology, there is sometimes a reluctance on the part of users to deal with the disruption and effort required to switch to a new, and perhaps previously untried system.

The successful development and integration of new sensing technologies is a pre-requisite for successful implementation of key EU policy goals such as achieving Good Environmental Status (GES) under the Marine Strategy Framework Directive. But these **high level policy goals do not necessarily create a market pull**.

The Ocean of Tomorrow OCEAN13 Topic 1 & 2 calls included the following:

- Due to growing concerns about the health of the oceans and their capacity to continue to provide resources, goods and services as well as associated risks to the human health, there is an increasing demand for real-time monitoring of the environmental status of marine water quality and the provision of early warning systems.

- There is an urgent need to improve the in-situ component of the ocean observing systems to achieve an appropriate and comprehensive understanding of the functioning of the marine environment at different geographic, temporal scales and the monitoring of marine and maritime activities to ensure their sustainable development.

Both points are well identified, but it is not clear where exactly is the demand to create the pull required to advance these innovations and who is responsible for creating it. For crucial policy goals such as achieving GES or implementing the UN Sustainable Development Goals, it may be necessary to use policy and regulation as a tool, possibly through setting specific technical standards, to boost demand for new marine sensing technologies. This may seem to be creating an artificial policy and regulation-driven market and imposing costs on individual nations. This should be considered in light of a broader question: **in the long-term, which will be more expensive: effectively monitoring the marine environment or failing to monitor it properly?**

Significant public funds have already been invested in the development of innovative technologies. It is necessary to ensure that what has been developed is thoroughly analysed in a post-project evaluation, fully documented and taken forward in order to **realise the full potential** of these projects and capitalise on the investment of public funds.

OCEAN OF TOMORROW MARINE SENSING PROJECTS: TECHNOLOGY OUTPUTS

PROJECT	SENSOR / INSTRUMENT NAME	TECHNOLOGY	TARGET
BRAAVOO	Label-free antibody-based immuno-sensing on innovative nano-optical platforms	Sampling & Analysis	General toxicity
BRAAVOO	Live bacterial bioreporters	Sampling & Analysis	Individual compounds of bacteria
BRAAVOO	Photosystem II fluorescence of marine algae	Sampling & Analysis	Compound classes of bacteria and toxicity
Common Sense	Microplastics Analyser	Monitoring	Microplastics
Common Sense	Mini-Seawater Sampling System (MISS)	Sampling	Multiple parameters
Common Sense	Sensor Web Platform	Data management	Sensor data
Common Sense	Smart Sensor Unit	Data transmission	Sensor data
Common Sense	Underwater Noise Sensor	Sampling	Underwater noise
Common Sense	Reference Sensor pH/CO2	Monitoring	Resistivity changes
Common Sense	Reference Sensor temperature	Monitoring	Temperature
Common Sense	Eutrophication Sensor	Monitoring	Chemical species
Common Sense	Heavy Metals Sensor	Monitoring	Heavy metals
EnviGuard	Algae Detection Unit (ADU)	Monitoring	Algae
EnviGuard	Chemical Detection Unit (CDU)	Analysis	Chemical species
EnviGuard	Pathogen Detection Unit (PDU)	Analysis	Pathogens
MariaBox *	MariaBox autonomous device for monitoring 4 pollutants and 4 biotoxins	Monitoring	Pollution
MariaBox *	Mariabox-CORE and related electronics	Control	Systems
MariaBox *	Mariabox-POW and Mariabox-COMM (power and communications modules)	Data transmission	Sensor data
MariaBox *	Mariabox-NET (cloud-based data management platform)	Data management	Sensor data

APPLICATION																	TRL LEVELS								
TEMPERATURE / PRESSURE	OXYGEN	SALINITY	CONDUCTIVITY	pH	TURBIDITY	ORGANIC MATTER	NUTRIENTS	ALGAE	HYDROCARBONS	CARBON CYCLE	FISHERIES	UNDERWATER NOISE	HEAVY/TRACE METALS	TOXINS	ANTIMICROBIAL AGENTS	MICROPLASTICS	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8	TRL9
						x		x					x	x											
						x		x					x	x											
						x		x					x	x											
																x	x	x	x	x	x	x			
x	x	x	x		x			x									x	x	x	x	x	x	x		
																	x	x	x	x	x	x			
																	x	x	x	x	x	x			
												x					x	x	x	x	x	x	x		
				x						x							x	x	x	x	x				
x			x														x	x	x	x					
							x										x	x	x	x	x	x	x		
													x				x	x	x	x	x	x			
								x									x	x	x	x	x				
														x			x	x	x	x	x				
														x											
x	x	x		x				x	x				x	x			x	x	x	x	x				
																	x	x	x	x	x	x			
																	x	x	x	x	x	x			
																	x	x	x	x	x	x			

PROJECT	SENSOR / INSTRUMENT NAME	TECHNOLOGY	TARGET
MariaBox *	Mariabox-MOB (mobile app)	Data management	Sensor data
MariaBox *	Mariabox buoy (new smart buoy developed in the project)	Platform	Systems
MariaBox *	Lab-in-a-disc design for 8 analytes, 3 samples each	Analysis	Sensors
MariaBox *	Biosensors for PFOS, Naphthalene, Heavy Metals and Camphechlor	Analysis	Pollution
MariaBox *	Biosensors for Saxitoxin, Microcystin, Azaspiracid and Domoic Acid	Analysis	Biotoxins
NeXOS *	Optical Sensor O3 - Carbon sensor system	Monitoring	Carbon cycle relevant parameters
NeXOS *	Optical Sensor O1 MatrixFlu-UV and MatrixFlu-VIS	Monitoring	Multiple parameters
NeXOS *	Optical Sensor O1 Minifluo	Monitoring	Polycyclic aromatic hydrocarbons
NeXOS *	Optical Sensor O2 - Phytoplankton identification sensor (OSCAR-G2)	Profiling	Phytoplankton groups
NeXOS *	Optical Sensor O2 - Phytoplankton identification sensor (HyAbs)	Profiling	Phytoplankton groups
NeXOS *	Acoustic Sensors (A1)	Profiling	Acoustic sources
NeXOS *	Acoustic Sensors (A2)	Profiling	Acoustic sources
NeXOS *	EAF-RECOPESCA sensor system	Monitoring	Multiple parameters
NeXOS *	Open source Sensor Web Platform based on interoperability standards	Data management	Sensor Data
NeXOS *	Helgoland Sensor Web Viewer (open source)	Data management	Sensor data
SCHeMA	All-solid-state ion selective electrode – pH	Monitoring	pH
SCHeMA	All-solid-state ion selective electrode – carbonate	Monitoring	Carbonate
SCHeMA	All-solid-state ion selective electrode – nitrate	Monitoring	Nitrate
SCHeMA	All-solid-state ion selective electrode – nitrite	Monitoring	Nitrite
SCHeMA	CSM: Multi-channel carbon species submersible probe	Monitoring	pH, Carbonate, Calcium
SCHeMA	NSM : Multi-channel nutrient submersible probe	Monitoring Alarm system	Nitrate, Nitrite

APPLICATION																	TRL LEVELS								
TEMPERATURE / PRESSURE	OXYGEN	SALINITY	CONDUCTIVITY	pH	TURBIDITY	ORGANIC MATTER	NUTRIENTS	ALGAE	HYDROCARBONS	CARBON CYCLE	FISHERIES	UNDERWATER NOISE	HEAVY/TRACE METALS	TOXINS	ANTIMICROBIAL AGENTS	MICROPLASTICS	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8	TRL9
																	X	X	X	X	X	X			
																	X	X	X	X	X	X	X	X	
																	X	X	X	X	X				
									X				X				X	X	X	X	X				
								X						X			X	X	X	X	X				
				X						X						X	X	X	X	X	X				
					X	X		X	X							X	X	X	X	X	X	X	X	X	
									X							X	X	X	X	X	X	X			
					X			X								X	X	X	X						
					X			X								X	X	X	X	X					
												X				X	X	X	X	X	X	X			
												X				X	X	X	X	X	X				
X	X	X			X						X					X	X	X	X	X	X	X	X	X	X
																	X	X	X	X	X	X	X		
																	X	X	X	X	X	X	X		
				X						X							X	X	X	X	X	X	X		
				X						X							X	X	X	X	X	X	X		
							X										X	X	X	X	X	X	X		
							X										X	X	X	X	X				
				X						X							X	X	X	X	X	X	X		
							X										X	X	X	X	X	X			

ALARM SYSTEM	NITRATE, NITRITE	TECHNOLOGY	TARGET
SCHeMA	AuNP- GIME for voltammetric quantification of bioavailable fraction of trace metals	Monitoring	As(III)
			As(V)
			Hg(II)
SCHeMA	TMSM: Multi-channel submersible trace metal sensing probe – Bioavailable fraction of trace metals	Monitoring / Profiling. Alarm system	Cu(II), Pb(II), Cd(II), Zn(II)
			As(III)
			Hg(II)
SCHeMA	ASM: Miniature multi-channel Algae Sensing probe (ASM	Monitoring Alarm system	Phytoplankton groups, Toxic algal species
SCHeMA	LED detector	Analysis	Saxitoxin
SCHeMA	IR-FEWS sensing system	Analysis	Volatile organic compounds
SCHeMA	NC: Network controller	Standardized control unit	Multi sensing probe integration and wireless control
SCHeMA	Web-based system and user interfaces based on interoperability standards	Sensing probe and data management	Sensing probe registration and localization. Data transmission, standardization, processing and dissemination
SCHeMA	Autonomous integrated observation system (CSM, NSM, TMSM, ASM, CTD, NC and web-interface)	Monitoring / profiling. Alarm system	Range of chemical and biological compounds coupled to master variables
Sea-On-A-Chip *	Real time immuno-sensor platform for measurement of concentrations (ng/l-microg/L) of selected contaminants.	Monitoring	Pollution (various)
SenseOCEAN *	Optodes for marine measurements	Monitoring	Chemical species
SenseOCEAN *	Lab on chip chemical sensors - Phosphate	Sampling	Phosphate
SenseOCEAN *	Lab on chip chemical sensors - Silicate	Sampling	Silicate
SenseOCEAN *	Lab on chip chemical sensors - Ammonia	Sampling	Ammonia
SenseOCEAN *	Lab on chip chemical sensors - Nitrate	Sampling	Nitrate
SenseOCEAN *	Lab on chip chemical sensors - Iron	Sampling	Iron
SenseOCEAN *	Lab on chip chemical sensors - pH	Sampling	pH

APPLICATION																	TRL LEVELS								
TEMPERATURE / PRESSURE	OXYGEN	SALINITY	CONDUCTIVITY	pH	TURBIDITY	ORGANIC MATTER	NUTRIENTS	ALGAE	HYDROCARBONS	CARBON CYCLE	FISHERIES	UNDERWATER NOISE	HEAVY/TRACE METALS	TOXINS	ANTIMICROBIAL AGENTS	MICROPLASTICS	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8	TRL9
													x				x	x	x	x	x	x	x		
													x				x	x	x	x					
													x				x	x	x	x	x	x			
							x						x				x	x	x	x	x	x	x	x	
													x				x	x	x	x	x	x	x		
																	x	x	x	x	x	x			
								x									x	x	x	x	x	x	x		
														x			x	x	x						
						x			x								x	x	x	x					
																	x	x	x	x	x	x	x	x	
																	x	x	x	x	x	x	x	x	
x	x	x	x	x	x		x	x		x			x				x	x	x	x			6 to 9 depending on parameters		
											x			x			x	x	x	x	x				
	x			x			x			x							x	x	x	x	x	x			
							x										x	x	x	x	x	x	x		
							x										x	x	x	x	x	x			
							x										x	x	x	x	x	x			
							x										x	x	x	x	x	x	x	x	
													x				x	x	x	x	x	x	x	x	
				x						x							x	x	x	x	x	x	x		

ALARM SYSTEM	NITRATE, NITRITE	TECHNOLOGY	TARGET
SenseOCEAN *	Autonomous Nutrient Electrochemical Sensor In Situ (ANESIS)	Monitoring	Silicate & Phosphate
SenseOCEAN *	Electrochemical CO_2 microsensor	Monitoring	CO_2
SenseOCEAN *	Electrochemical N_2O microsensor	Monitoring	N_2O
SenseOCEAN *	Electrochemical High-sensitivity N_2O (STOX-N_2O)	Monitoring	N_2O
SenseOCEAN *	Multiparameter optical sensor	Monitoring	Multiple parameters
SMS*	Fully automated Integrated system for toxic algae detection (optical)	Monitoring	Toxic algal species
SMS *	Fully automated Integrated system for phytotoxin detection (optical)	Monitoring	Phytotoxins
SMS *	Optical sensor for sulfonamides and derivatives (optical)	Analysis	Sulfonamides
SMS *	Multiparameter optical sensor	Monitoring	Nutrients

* At the time of going to press only those projects marked with an asterisk have been recently validated by the COLUMBUS project. For those projects not marked by an asterisk the information presented has been acquired from various publicly available sources, however there may be more recent information that has not yet been published.

	APPLICATION																	TRL LEVELS								
	TEMPERATURE / PRESSURE	OXYGEN	SALINITY	CONDUCTIVITY	pH	TURBIDITY	ORGANIC MATTER	NUTRIENTS	ALGAE	HYDROCARBONS	CARBON CYCLE	FISHERIES	UNDERWATER NOISE	HEAVY/TRACE METALS	TOXINS	ANTIMICROBIAL AGENTS	MICROPLASTICS	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8	TRL9
								x										x	x	x	x	x	x	x		
											x							x	x	x	x	x	x			
								x										x	x	x	x	x	x	x	x	x
								x										x	x	x	x	x	x			
	x					x	x	x	x	x								x	x	x	x	x	x	x	x	x
									x									x	x	x	x	x	x			
															x			x	x	x	x					
																x		x	x	x	x					
								x										x	x	x	x	x	x	x	x	x

Maritime Sensor Technologies for the European Market: Research, Development and Implementation

Good practice guide

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COLUMBUS

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COLUMBUS
KNOWLEDGE TRANSFER FOR BLUE GROWTH

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Good practice guide

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