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ERA-MBT Foresight Report

Work Package 2

Strategy for the marine biotechnology ERA-NET and beyond in the context of the European Bioeconomy

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PREFACE

The importance of marine biotechnology to European targets to build a bioeconomy is well documented. The scope of marine biotechnology is no longer confined to marine applications; it embraces a much wider set of activities that create value for the enterprise sector and benefits for wider society. Marine biotechnology both drives and includes significant innovation. It has an increasing potential to create jobs across different industries, many of them quite distant from the marine.

In responding to Europe's strategy for 'blue growth" the marine biotechnology ERA-NET is working with policy, business and research communities on long-range plans to strengthen marine biotechnology capabilities and competencies. This foresight exercise, in this case termed an OUTLOOK process, conducted by the ERA-MBT project highlights future research and innovation areas that need to be addressed to allow European industry to benefit from marine biotechnology. The analysis and vision in this report will help ERA-MBT to continue to expand its influence on marine biotechnology developments.

EXECUTIVE SUMMARY

The EU Research Framework Programme supported ERA-NET, ERA-MBT brings together 19 partners from 14 countries across Europe to work with all stakeholders to identify needs and gaps in the value chain, from research and development, through optimising research results for proof of concept and industrial uptake and valorisation of marine bio-resources. The ERA-MBT project was launched in December 2013 and will operate until the end of 2017. The objectives of ERA-MBT are to:

- Stimulate trans-European marine biotechnology research, innovation and enterprise activity.
- Build communities and capacity considering the maritime regions' different perspectives and potential.
- Deliver a lasting network to fund and support marine biotechnology research and enterprise activity.

Amongst the many other actions being undertaken by the project is the development of a strategic roadmap for marine biotechnology research and innovation. A key contribution to this plan to use a foresight type exercise to develop a perspective on the future of marine biotechnology research, technology, development and innovation (RTDI).

Discussions between the ERA-MBT project team and leading foresight practitioners concerning the feasibility of initiating a foresight study, led to the development a modified foresight approach, termed "OUTLOOK" by the ERA-MBT project partners. The core of this approach was to present an expert panel with specific questions, as opposed to the typical open-ended foresight process.

The "Societal Challenges" described in Horizon 2020 provided a context in framing questions about the future contribution of marine biotechnology related research to Europe's goals for societal and economic progress. The most relevant of these challenges to the ERA-MBT project include health, demographic change and wellbeing; food security, sustainable agriculture and forestry, marine and maritime and inland water research and the bioeconomy; secure, clean and efficient energy; climate action, environment, resource efficiency and raw materials; and Europe in a changing world – inclusive, innovative and reflective Societies.

An earlier scoping study for the foresight element of the ERA-MBT project had identified the two main questions as guidance for the OUTLOOK panel discussions,

1. **Where should marine biotechnology RTDI be focused in order to maximise the value from exploiting marine biomass?**
2. **What role is there for funding networks in supporting future marine biotechnology activities?**

These questions were developed to assist an expert panel to "develop and describe a set of scenarios that summarise the situation and role of marine biotechnology in the year 2030 in respect of its likely contribution to the achievement of successful outcomes to Europe's societal challenges".

The OUTLOOK panel identified two main drivers of future marine biotechnology research and innovation; the need to ***access*** marine biological resources and the ***demand*** of society for new

materials, biomass, exploration, infrastructure etc., These drivers provided a framework for four scenarios as outlined termed "Voyage of Discovery", "Ocean of Plenty", "Treading Water" and "Sea Mist".

The "**Voyage of Discovery**" highlights the challenges of exploring the marine for novel materials amongst the rich biological and environmental diversity of the world's oceans. In doing so, it points to possible areas where marine biotechnology can unlock the chemical and genetic potential of marine organisms and the importance of developing tools and processes to support the activity. Earlier successes in harvesting novel materials from marine species, drives the search for new organisms from even more remote regions and for actions that support an expansion of ocean bioprospecting. It points to the emergence of specialist firms that engage in bioprospecting and of the creation of research networks to commercialise marine origin materials in a growing number of novel applications related to health, increased food supply and advanced materials.

The scenario of the "**Ocean of Plenty**" draws attention to exploiting available biomass. It describes the use of marine biomass, largely generated from cultivated sources in a wide range of areas, all of which are enabled by biotechnological driven refining processes. Marine biomass feeds the European bioeconomy. There is a wide level of acceptance throughout society that marine origin materials contribute to meeting the immediate needs of society – and doing so in harmony with the environment. Indeed, in this scenario marine biotechnology is identified as having increased our knowledge of marine environments. The "Ocean of Plenty" points to the efficient and sustainable production of marine biomass. Because of the demonstrated successes in sustainably managing biomass production, barriers to entry to marine areas are low.

The scenario for "**Treading Water**" is a future where marine biotechnology research is essentially static and constrained by concerns about the impact of biotechnology and associated products on the marine environment. Though demand for natural products is increasing and linked to improved lifestyles, European efforts to expand marine biomass production to areas outside food production are seen as threats to what is a stable, sustainable marine foods production system based upon harvesting limits. Biomass production systems are tightly controlled and monitored, however, where producers can demonstrate compliance with regulatory systems and guidelines, entry barriers are low. Contributing to the concept of "sustainability" are processing systems that extract value from all components of marine species. As a result of these successes, new opportunities arise for research collaboration that focuses on the use of marine biotechnology for environmental monitoring and bioprocessing.

The final scenario, "**Sea Mist**", is set within an affluent European society that is sceptical about role of science and technology in supporting life-style choices. At best there is an indifference to exploiting marine bio-resources for purposes other than food. There are clear indications in this scenario that limits are imposed on marine biomass production to ensure negative environmental events of the past are not repeated. The scenario reflects a global priority - food production - and clearly establishes a role for aquaculture in meeting the demand for marine foods. All marine foods – fish, shell fish and algae are seen as inherently "functional", conveying benefits over and above those associated with basic nutrition. At a time when the core of marine biomass production is directed towards food applications, aquaculture output has spiralled, heralding the development of natural, sustainable feed and disease treatments. New pathogens and other threats to aquaculture emerge from climate change. This stimulates environmental and veterinary research designed to

combat such threats. Societal concerns about the marine environment and over exploitation are addressed in environmental policy directives.

The four scenarios do not attempt to predict the future, they describe possible future situations within which marine biotechnology research and innovation needs and opportunities could be explore. The OUTLOOK panel identified specific research challenges that require to be resolved if the broad potential and promise of marine biotechnology is to be realised that are described within five thematic research areas for future marine biotechnology RTDI; "Exploration"; "Biomass Production and Processing"; "Product Development and Diversification"; "Enabling Technologies and Infrastructure" and "Policy Support and Stimulation". The research challenges are described below.

EXPLORATION

Research activity under the theme of exploration includes activity that will target, identify and assess marine organisms and develop systems to support the collection of new organisms in unexplored habitats as well as enable more specific and thorough evaluation of known and available organisms. Increasing the rate of discovery of new bioproducts is essential if the potential for marine biotechnology to contribute to commercialisation activity is to be realised. Preferred research topics include,

- Continuing to target microorganisms from deep sea sediments, microbial symbionts from sponges and other organisms; macro and micro algae; bivalves, fish and fish processing discards, and marine fungi as sources of biologically active natural products.
- The discovery of new marine species including microorganisms, as a source of novel materials.
- Exploiting the potential of genetic resources in the discovery process.
- Exploring the chemical and biological diversity of marine organisms.

BIOMASS PRODUCTION AND PROCESSING

Principle research challenges in biomass production and processing include increasing the production of marine biomass, establishing the controlled culture of marine biomass; creating efficient transformation and refining processes; reducing the complexity of the supply chain by integrating biomass production and refining, reducing energy demand in processing marine biomass and enhancing the sustainability of the marine biomass conversion by minimising the creation of waste. Specific research topics that contribute to meeting these challenges include,

- Increasing the production of biomass from sustainable marine resources, including exploring the potential to develop off-shore and deep water aquaculture.
- Establishing the controlled culture of marine biomass at sea and on land, including developing techniques to culture marine organisms not currently in culture.
- Creating efficient transformation and refining processes, including concepts of multi-stream inputs and bio refining of mixed biomass feedstock.
- Reducing the complexity of the supply chain by integrating biomass production and refining, reducing energy demand and waste in processing marine biomass.

- Removing bottlenecks in marine biomass transformation and conversion by identifying marine enzymes that can modify the structure of biomass, tailor its chemical and biological properties and reduce the energy demand of transformation.
- Engaging in research to support the expansion of cultured biomass production including measures to minimise and mitigate environmental impacts; addressing waste management; enhance biosecurity and the introduction of new production systems (including breeding/hatchery/genetics/nutrition and health) including the use of molecular methods.

PRODUCT DEVELOPMENT AND DIVERSIFICATION

High expectations exist about the potential of Europe's bioeconomy to contribute to addressing societal challenges and the achievement of economic growth. Marine biotechnology is a cross-cutting and enabling technology that is capable of supporting efforts to bring about greater efficiencies in the optimal and sustainable use of biological resources. The cross-cutting, multidisciplinary nature of marine biotechnology research makes it highly relevant to the efforts of different industry sectors to develop competitive, sustainable, safe and innovative products and processes. Supporting economic progress and helping to meet societal needs is research that will,

- Assess, profile, and maximise the sustainable use of marine bio-resources for applications in human and animal food, as food ingredients, therapeutic compounds, medical devices and biomaterials, cosmetics and cosmeceuticals and as novel industrial materials and processes.
- Further isolate and analyse materials from marine biomass to enhance the understanding their structures and modes of action in human and animal health and food/feed related areas.
- Create novel biosensors based on marine derived materials or marine organisms and explore their use in monitoring the status of marine environments and the safety of marine origin foods.
- Assess the potential of marine origin materials to contribute to improve aquaculture performance including addressing health and disease issues within cultured populations, disease resistance and minimising environmental impacts of production.
- Target new research to identify novel proteins, polysaccharides, lipids, sterols, pigments and antioxidants from marine biomass.
- Investigate the inherent biocompatibility of some marine materials and assess their potential for use in medical devices, for drug delivery or in the repair, replacement or regeneration of tissue.
- Harness the potential of marine organisms to act as experimental models in health related research.

ENABLING TECHNOLOGIES AND INFRASTRUCTURE

Realising the future benefits of marine biotechnology requires access to, and continuous investment, in research infrastructures. Research and development networks and collaborations that create the multi-disciplinary research effort required to engage in marine biotechnology and enable technology transfer also need to be encouraged. Marine biotechnology research is largely reliant on contributions from across the scientific and technological horizon to provide the all-essential "tool-kit" necessary in exploring marine environments and developing new marine origin products. Through measures which encourage the convergence of different disciplines, technologies and

industry sectors, it will be possible to strengthen marine biotechnology research and innovation. Areas of research required to develop lasting supporting infrastructures includes,

- Develop alternatives to the traditional collection or harvesting of marine organisms, including the development of methods to allow in-situ assessment and screening of marine organisms to increase the rate of the discovery of novel materials.
- The development of predictive tools to improve the identification and targeting of biological "hot-spots" in the oceans.
- Identify and build new competencies and networks to support marine biotechnology research and innovation.
- Developing deep-sea equipment for use in habitat mapping and biological resource assessment.
- Reducing the costs associated with discovery related activities.
- Harnessing knowledge and expertise from other sectors of the bioeconomy to support the rapid development of pilot scale equipment and scale-up of marine biomass refining.
- Assessing the potential for shared and open access marine data and biological repositories.

POLICY SUPPORT AND STIMULATION

The research areas and opportunities identified in the policy arena do not all require marine biotechnology research actions, other research competencies e.g. in the socio-economic, environmental and international law also contribute to advancing the creation of policy to support marine biotechnology activities.

- Identify ways to expand access to marine bioresources for discovery purposes in European waters and on the high seas.
- Develop a comprehensive planned policy research programme to apply the knowledge gained from marine biotechnology research to inform public policy, governance and regulation of marine environment and marine derived products.
- Support the introduction of common regulations across member states regarding the harvesting, culture and exploitation of marine biomass.
- Establish efficient and responsive regulation and policy development relating to marine bioresources.
- Identify mechanisms to attract greater industry participation in marine biotechnology related research.
- Identify policy developments to advance marine biomass production and processing capabilities and to reduce barriers to the development of new markets for marine derive products.

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INTRODUCTION

The marine environment comprises many environmental niches that are home to a rich source of species. Because these species have evolved to live in diverse environments with variations in salinity, temperature, light and pressure, they are themselves an extremely rich source of chemical and bio-chemical diversity that can have applications in numerous novel products and processes. The starting point in extracting value from marine bio-resources is the collection, culture and harvesting of available marine biomass. Marine biotechnology is a knowledge generation and conversion process: it unlocks access to biological compounds and creates novel uses for them e.g. a new pharmaceutical; a novel enzyme; new process or biomaterial; food or food ingredient and in doing so builds significant competitive advantage, stimulates economic growth and creates new jobs.

Marine biotechnology sometimes referred to as "blue biotechnology", is a key enabling technology within the context of the broader bioeconomy. It is a multi-disciplinary, knowledge and capital-intensive technology that contributes to and spans different sectors. It exploits the diversity found in marine environments in terms of the form, structure, physiology and chemistry of marine organisms, many of which have no terrestrial equivalents. And by exploring and harnessing marine materials, creates entirely new uses for them. Already there are successful marine origin pharmaceuticals, novel industrial enzymes, food ingredients, biosensors, drug delivery systems and new chemical compounds.

Europe's Bioeconomy is focused on the conversion of renewable resources from terrestrial and marine environments into food, animal feed and related biobased products and is seen as contributing to the realisation of Europe's grand challenges for the 21st century. Europe's Blue Growth Strategy, which describes 'opportunities for marine and maritime sustainable growth' was published in 2012 [1]. It contains five distinct areas, of which, marine biotechnology termed 'blue biotechnology', is one. Blue Growth is embedded in the overarching 'Bioeconomy Strategy for Europe' adopted by the EC. There is long-standing and persistent reference to the scope of marine biotechnology within policy and research communities; with various attempts being made to highlight the opportunity for "blue biotechnology" in contributing to meeting the societal and other challenges which face Europe.

A major challenge faced by the Marine Biotechnology ERA-NET project (ERA-MBT) consortium in delivering the EU 7th Framework Programme supported project is developing a strategic roadmap for marine biotechnology, which is coherent in its links to related and broader European initiatives such as Horizon 2020, plans for the development of a European Bioeconomy and more specifically, Europe's Blue Growth Strategy; whilst at the same time, providing a direction and focus on actions that support an increasingly innovative industry.

The Marine Biotechnology ERA-NET initiated various activities to develop insights to marine biotechnology research and innovation. Together they are designed to enhance our understanding

[1] http://ec.europa.eu/maritimeaffairs/policy/blue_growth/

how and where marine biotechnology can add value to marine biomass and in doing so, to clarify its role in contributing to Europe's broader industrial and economic priorities.

Despite the excellent progress by way of increased visibility of marine biotechnology, new policy direction and dedicated research funds for marine biotechnology and related research, many of the challenges highlighted in previous fora remain. Amongst the most challenging of these for ERA-MBT is the development of a strategic roadmap: the steps required in defining and prioritising Europe's future marine science and marine biotechnology research activity; securing a greater participation by industry as a potential user of outputs from marine biotechnology research; improving the funding and co- ordination of marine science and targeting resources at marine biotechnology; and encouraging Europe's best scientists to engage in marine biotechnology research.

Just as European innovation systems are being challenged by the rate of technology developments and the continuous rapid global change, marine biotechnology is similarly challenged. ERA-MBT undertook a foresight study in order to create an awareness of potential long-term developments and challenges that may impact on future marine biotechnology RTDI activity. Adopting this approach to understand and manage assumptions about future developments is used extensively in strategic decision making. The process initiated by ERA-MBT was not an attempt to predict the future – rather it was an opportunity to be somewhat prepared to deal with possible future situations. It was used by ERA-MBT to uncover potential marine biotechnology RTDI areas, contributions to enhance the quality of life, build on Europe's industrial and academic competencies and develop insights to the future challenges in managing marine environments. Together, these insights provide a knowledge base that will be drawn upon in defining the marine biotechnology strategic roadmap.

GOALS AND OBJECTIVES OF THE ERA-MBT PROJECT

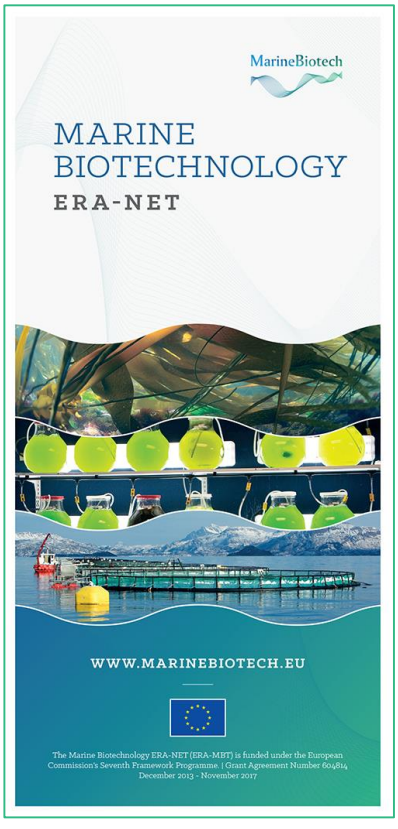
The Marine Biotechnology ERA-NET recognises that Europe's marine ecosystems and organisms are largely unexplored, understudied and in parts underutilised, in spite of Europe's access to an extensive and diverse set of marine ecosystems that support an enormous marine biodiversity. This resource, through the coordinated application of marine biotechnology, has the potential to provide a major contribution towards addressing some of the most pressing societal challenges including environmental degradation, human health and delivering sustainable supplies of food, food ingredients and other novel materials in response to meeting the Grand Challenges for our future.

ERA-MBT brings together 19 partners from 14 countries across Europe to work with all stakeholders to identify needs and gaps in the value chain, from research and development, through optimising research results for proof of concept and industrial uptake and valorisation of marine bio-resources. The ERA-MBT project was launched in December 2013 and will operate until the end of 2017. The objectives of ERA-MBT are to:

- Stimulate trans-European marine biotechnology research, innovation and enterprise activity.
- Build communities and capacity considering the maritime regions' different perspectives and potential.
- Deliver a lasting network to fund and support marine biotechnology research and enterprise activity.

During its lifetime ERA-MBT will,

- Launch at least three thematic calls to generate joint European research and development activities.
- Hold stakeholder events to promote dialogue between science, industry and policy and to identify main challenges for successful development of marine biotechnology.
- Establish an International Advisory Group from the scientific, policy and business sectors to guide ERA-MBT actions.
- Identify synergies and avoid overlap with other activities sharing common interests with ERA-MBT.
- Develop a perspective on the future of marine biotechnology research, technology, development and innovation (RTDI).
- Develop a strategic roadmap.
- Provide an open-access portal as a source of information on marine biotechnology.
- Develop a lasting network of European funding agencies and stakeholders.



WHAT IS MARINE BIOTECHNOLOGY?

Biotechnology is the process by which biological systems are controlled, manipulated or modified to enable the production of value–added products. The impact of biotechnology is already seen in traditional industries such as food and beverages, where it is bringing about changes in how products are produced and influences the kind of products that can be produced. It is also driving the development and application of entirely new production systems to support the industrial scale production of pharmaceuticals, other chemicals, and food as well as a host of novel materials with a wide range of applications. Biotechnological processes are yielding novel approaches for the processing of waste materials. It is likely, as a result of advances in biotechnology, that entirely new business sectors will emerge as efforts to maximize biological diversity intensify.

Marine Biotechnology is a key enabling technology within the context of the broader bioeconomy. It is a multi-disciplinary, knowledge and capital-intensive technology that contributes to and spans different sectors. In doing so, it provides new opportunities for industry to further develop significant competitive advantage, stimulate growth and create new jobs.

Marine biotechnology sometimes referred to as "blue biotechnology", exploits the diversity found in marine environments in terms of the form, structure, physiology and chemistry of marine organisms, many of which have no terrestrial equivalents, in ways that enable new materials to be realised. Marine biotechnology is a knowledge generation and conversion process: it unlocks access to biological compounds and provides novel uses for them. By exploring and harnessing marine materials, entirely new uses in areas far from the marine are likely to be found. Already there are successful marine origin pharmaceuticals, novel industrial enzymes, food ingredients, biosensors, drug delivery systems and new chemical compounds.

This search for novel materials and new marine organisms stimulates new methods of exploring and exploiting our marine resources and can enable innovative technologies that improve our ability to sustainably harvest marine resources. Though little of the marine biosphere has been sampled, European discovery-oriented research in deep waters identified novel micro-organisms, viruses, bio molecules and bacteria.

THE MARINE RESOURCE

Our oceans and seas cover more than 70 percent of the earth's surface and 95 percent of the biosphere. The marine environment comprises many environmental niches that are home to a rich source of species. Because these species have evolved to live in diverse environments with variations in salinity, temperature, light and pressure, they are themselves a source of chemical and bio-chemical diversity that can have applications in numerous novel products and processes. Marine biotechnology enabled products are based on exploiting the biological diversity of marine environments.

THE MARINE BIOTECHNOLOGY "TOOL-BOX"

Marine biotechnology is concerned with the discovery and exploitation of biological materials from marine environments. Such materials are known to have the potential to form the basis of new products and processes in a wide array of industry sectors. The fisheries and aquaculture sectors employ marine biotechnological processes in the development of sustainable marine food sources. Developing insights to the genetic and biochemical composition of materials and processes from marine sources; deepening our understanding of environmental and other factors which brought them about; and understanding their positioning and role within the marine ecosystem; are fundamental to realising their economic and societal potential.

Many techniques are employed to isolate, assess, process and characterise natural compounds from marine sources. Accelerating the discovery process requires support from, and access to, underpinning scientific areas of marine biology, botany, microbiology, biochemistry, molecular biology, genetics and natural products chemistry. Research in these areas not only contributes to improving our understanding of marine origin materials, but also creates new and improved tools and defines the protocols on which biological and genetic libraries can be built. Expertise in gene sequencing, bioinformatics, post-genomics, functional genomics, transcriptomics, proteomics, protein structures, metabolomics, and assays to assess bioactivity, all contribute to the search for novel biomaterials, proteins, enzymes and safe, sustainable and healthy food from marine organisms. A schematic of the "marine biotechnology tool-box", adapted from the concept developed in the Marine Board Position Paper 19 is given below.

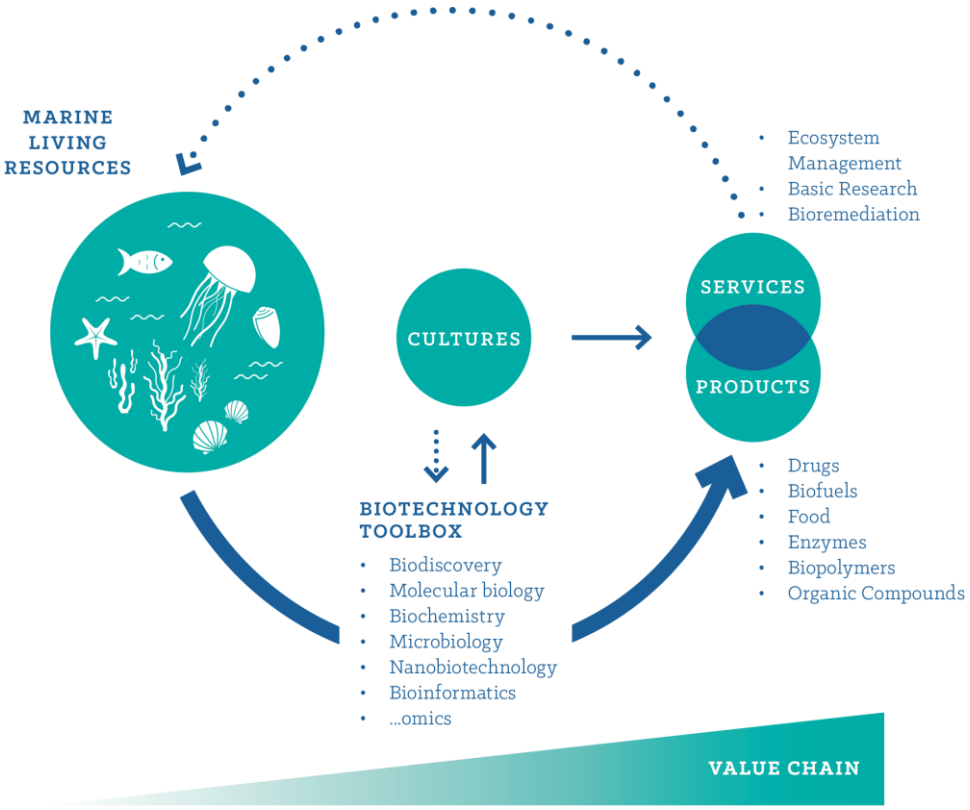


Figure 1: Marine Biotechnology workflow

A CONTEXT TO THE "FORSIGHT" STUDY ON FUTURE MARINE BIOTECHNOLOGY

A key deliverable of the ERA-MBT project is the development of a strategic roadmap; a plan informed by a number of different interventions including stakeholder workshops, targeted surveys, desk studies and a "foresight" type study. Together, contributions from these activities will provide guidance to the identification and definition of research themes. These feedback mechanisms will also generate insights to help funding agencies to identify new funding opportunities and measures to support future marine biotechnology related research and innovation and contribute to building stronger funding networks.

Discussions between the ERA-MBT project and leading foresight practitioners concerning the feasibility of initiating a foresight study, led to the development a modified foresight approach, termed "OUTLOOK" by the ERA-MBT project partners. Feedback from these discussions helped to clarify and confirm the planned approach and stressed the importance presenting an expert panel with specific questions, as opposed to the typical open-ended foresight approach; limiting the size of the panel to less than 20 persons, providing a comprehensive briefing in advance of the workshop and recruiting an experienced facilitator. The OUTLOOK process was further refined taking account of the external input and identifying persons from diverse backgrounds to be recruited to form the OUTLOOK panel.

The structure and timeframe of the ERA-MBT project is such that many of the project's actions and deliverables required strategic direction and insights to either initiate or complete them. The importance of a strategic roadmap for marine biotechnology was highlighted as an early and enabling deliverable, requiring an array of inputs that included contributions from a foresight type exercise.

SOCIETAL CHALLENGES

The "Societal Challenges" described in H2020 [2] provide a context to the questions about the future contribution of marine biotechnology related research to Europe's goals for societal and economic progress. The most relevant of these challenges to the ERA-MBT project include health, demographic change and wellbeing; food security, sustainable agriculture and forestry, marine and maritime and inland water research and the bioeconomy; secure, clean and efficient energy; climate action, environment, resource efficiency and raw materials; and Europe in a changing world – inclusive, innovative and reflective Societies. Leadership in enabling and industrial technologies (LEIT), a current H2020 theme, is also relevant to the OUTLOOK exercise, since it aims to build and maintain global leadership in technologies that underpin competitiveness across a range of existing and emerging European industries and sectors. Marine biotechnology, through its potential in locating, identifying and using novel biological materials from the marine environment as the basis for new products and processes, can also contribute to Nanotechnologies, Advanced Materials, Biotechnology and Advanced Manufacturing and Processing.

Also relevant to the future role of marine biotechnology is to consider it in the context of Science with and for Society. This H2020 theme seeks to build cooperation between science and society by targeting issues such as the recruitment of new scientific talent and ensuring those engaged in scientific research, do so responsibly, whilst displaying a strong social awareness. This merging of societal actors within the research and innovation process lays a foundation for building *Responsible Research and Innovation* (RRI).

[2] http://ec.europa.eu/programmes/horizon2020/en/h2020-section/societal-challenges

FUTURE TRENDS RELEVANT TO MARINE BIOTECHNOLOGY AND THE GRAND-CHALLENGES

Developing possible scenarios for European marine biotechnology requires insights to factors that may shape how the world might look in 2030. It is outside the scope of the ERA-MBT project to engage in an extensive futures study required to paint such a picture of the world. Fortunately, others publish their view on the global megatrends; one such report from strategy consultants Roland Berger [3] covers the period to 2030. There is no certainty regarding how the world may, or may not develop, as well as a myriad of models and ideas on how these views can be developed. There are possibly as many examples of what the "visionaries" or "futurists" said about the future turning out as being totally wrong, as there were instances of them getting things right. Natural, political and technological events can occur quite unexpectedly, resulting in changes in how the world functions and have major impacts - both positive and negative, on society.

As imperfect such a map of the future might be, it is useful to have some map, rather than be totally blind in looking at the potential of marine biotechnology. Table 1 below comprises extracts of megatrends from the Roland Berger Compendium that are viewed as relevant to the OUTLOOK exercise and useful in the context of developing scenarios.

[3] Trend Compendium 2030, Roland Berger Strategy Consultants 2014

Table 1: Extracts of megatrends from the Roland Berger Compendium

MEGATREND	SUBTREND
Changing demographics	• A growth in world population to 8.3 billion people • An aging society as the median age rises 5 years to 34 years • Increasing urbanisation reflected in 59% of the world living in cities
Globalisation and future markets	• Continued globalisation with exports and FDI [4] growing faster than GDP [5] • Emergence of BRICs [6] as new powerhouses - GDP growth of 7.95 p/a • Growth of 5.9% in the NEXT 11 [7] and strong growth in ASEAN 5 [8]
Scarcity of resources	• Increase in primary energy consumption of 26% • Half the world will live in areas of high water stress i.e. shortage • Some rare metals will run out • Rising food demand
Climate change	• Continued increase in CO2 emissions – by 16% • Average global temperature to rise by 0.5 – 1.5 deg C • Declining biodiversity and increase in extreme weather events
Technology and innovation	• Extensive diffusion of technology – at high speed across the globe • Innovations will change our lives robotics and the internet of things [9] • The age of life sciences – challenged by demographics boosted by R&D
Global knowledge society	• Know-how base increases as 55% of population complete at lease 2nd level education • Gender gap narrows • ”War” over talent as demand for qualified people exceeds supply
Sharing global responsibility	• A shift to global cooperation as nations share responsibility • Number of and power of NGOs will grow significantly • Increase in philanthropic donations but philosophy of giving will change

[4] Foreign Direct Investment
[5] Gross Domestic Products
[6] Brazil, Russia, India and China
[7] Bangladesh, Egypt, Indonesia, Iran, Mexico, Nigeria, Pakistan, the Philippines, Turkey, South Korea and Vietnam
[8] Association of Southeast Asian Nations - Indonesia, Malaysia, Philippines, Thailand, Vietnam
[9] Internet of things – communications/sensors embedded within common artefacts

ERA-MBT FORSIGHT – "OUTLOOK"

Developed within the ERA-MBT, OUTLOOK is a "foresight type" process used by the ERA-MBT project to create a long-term view of how, and where, marine biotechnology is likely to contribute to the realisation of Europe's grand societal challenges by maximising the impact of research funds provided by the EU's research programme Horizon 2020. The focus of research funds provided under Horizon 2020 is towards research that will address Europe's grand challenges including sustainable agriculture, food security, resource efficiency and the bio-economy, as well as health and well-being for an aging population. There is a strong emphasis in Horizon 2020 on research and innovation funding for biotechnology and ensuring research outputs are commercialised in ways that benefit Europe's citizens and its economy.

Against this development background, the ERA-MBT project harnessed contributions from a high-level panel in response to specific marine biotechnology related questions. This approach contrasted sharply to the more traditional open-ended foresight exercise, which typically last for several months and include many panel meetings.

INTRODUCTION TO OUTLOOK

Faced with time and financial limitations, the ERA-MBT consortium developed a modified version of foresight to explore future scenarios for marine biotechnology based on the contribution of marine biotechnology research and innovation to supporting the societal challenges as outlined in Horizon 2020. Termed "*OUTLOOK"*, this process provided

1. A perspective on the contribution of marine biotechnology research to the achievement of these challenges and;
2. The key characteristics of a marine biotechnology network required to support the achievement of these grand challenges.

In addition to the use of outputs to inform the development of a strategic research agenda for marine biotechnology, they are recognised as possibly having a much broader application including, informing the definition of research calls from within ERA-MBT, as inputs to the H2020 Programme Committee in addition to DG Research and DG Mare, and used by national research funding agencies in helping them to direct research funds to prioritised research areas.

OUTLOOK – THE PROCESS

The OUTLOOK process is built around three stages; a scoping activity, a one-day facilitated workshop, and the production of a report that describes the outputs from the workshop. Each of the three steps are summarised below:

- SCOPING: This pre-workshop stage completed by the ERA-MBT partners delivered a document to provide the scope and context to the exercise, give insights to key trends and facts related to marine biotechnology, an analysis of the current situation of European marine biotechnology activity and define the questions to be addressed in the workshop.
- WORKSHOP: This one day facilitated event considered the key questions with a view to describing likely scenarios for marine biotechnology in the year 2030; identify possible threats; highlight areas of opportunity that require to be developed to meet societal challenges; highlight the key characteristics of marine biotechnology funding networks; and establish a vision for future marine biotechnology RTDI.
- OUTPUT: The ERA-MBT management is responsible for delivering a report based on the findings of the workshop.

THE KEY QUESTIONS

The challenge facing the OUTLOOK panel was,

> *To develop and describe an a set of scenarios that summarise the situation and role of marine biotechnology in the year 2030 in respect of its likely contribution to the Achievement of successful outcomes to Europe's societal challenges.*

An earlier scoping study for the foresight element of the ERA-MBT project had identified the following main and subsidiary questions as guidance for the OUTLOOK panel discussions.

Where should marine biotechnology RTDI be focused in order to maximise the value from exploiting marine biomass?

- What route should marine biotechnology activities follow in order to maximise its potential to contribute to meeting each of the Societal Challenges by 2030?
- In what areas and in what ways will marine biotechnology impact on the lives of European citizens in 2030?
- What conditions are necessary in 2030 to enable Europe's enterprise sector to benefit from marine biotechnology research?

What role is there for funding networks in supporting future marine biotechnology activities?

- What funding models are most likely to support marine biotechnology RTDI in 2030?
- What steps could funding agencies/networks take to help to overcome the prime scientific, technological and financial challenges that may inhibit future marine biotechnology research, innovation and development?

STRUCTURE OF THE "OUTLOOK" WORKSHOP

The workshop started with an extended briefing session attended by the panel, the ERA-MBT project team and the facilitator. This meeting provided the first opportunity for the panel to seek clarification or ask questions relating to their role in the OUTLOOK process and to establish a working relationship with each other, the facilitator and with the ERA-MBT project personnel. The panel met formally on the 2nd December 2014, after which the ERA-MBT team engaged in follow-up actions with the facilitator and panel members to review the materials generated during the workshop.

METHODOLOGY

A briefing document prepared by the ERA-MBT team was sent to panel members in advance of the OUTLOOK workshop. The objective of the briefing document was to ensure a common understanding of marine biotechnology and the role of the ERA-MBT project in facilitating its development. In outlining the policy background to marine biotechnology and its position within the broader "bioeconomy", the document provided insights to how countries outside Europe view and make use of marine biotechnology. Since global factors are likely to influence, as well as be influenced by marine biotechnology, insights to possible global trends from leading strategy consultants Roland Berger [10] were included in the briefing document. This document described the challenges identified by ERA-MBT, as possibly providing marine biotechnology with opportunities to address them. The inclusion of insights to the Horizon 2020 societal challenges identified as opportunity areas for marine biotechnology, together with descriptions of marine bio-resources and biomass and of the marine biotechnology toolbox, provided the panel with a common marine biotechnology reference framework.

The goal of the OUTLOOK process was to create a set of likely or possible scenarios describing the marine biotechnology RTDI landscape in the year 2030. No right or wrong answer would be embedded within or inferred by the scenarios. The scenarios would result from the convergence of an informed debate around the key questions concerning the likely challenges faced by marine biotechnology. The facilitated workshop, comprising the following was at the heart of the OUTLOOK process.

- INTRODUCTION: ERA-MBT and the role of OUTLOOK in the project; insights to the process, introducing members of the OUTLOOK panel and the facilitator and a summary of the current trends and issues in marine biotechnology (Led by: ERA-MBT)
- WORKSHOP REQUIREMENTS: an outline of the day's agenda, working methodology and expectations regarding participation, break-out groups, housekeeping (Led by: Facilitator)
- SOCIETAL CHALLENGES AND QUESTIONS: a recap on the challenges and key questions, clarification of any points regarding their use in OUTLOOK (Led by: Facilitator)

10 Trend Compendium 2030, Roland Berger Strategy Consultants 2014

- RESEARCH 2030: three breakout groups each discussed the questions from an RTDI perspective and formulate initial thoughts/feedback/key points: the groups combined and worked to extract a set of key factors likely to influence the marine biotechnology RTDI environment. A member(s) of ERA-MBT supported each breakout group.
- FUNDING 2030: three breakout groups each discuss the questions from a funding perspective and formulate initial thoughts/feedback/key points: the groups combined and worked to extract a set of key factors likely to influence the marine biotechnology FUNDING environment. A member(s) of ERA-MBT supported each breakout group.
- PLENARY SESSIONS were held at the end of the research and funding discussions at which groups combined to discuss and agree on key factors likely to influence marine biotechnology research and funding activity; and to. considered text for four scenarios that describe the European marine biotechnology landscape in the year 2030.

WORKSHOP OUTPUTS

Feedback from the OUTLOOK workshop comprised copies of presentations from the break-out groups and plenary sessions, notes taken by the facilitator and the ERA-MBT team, as well as video film. The ERA-MBT team participated in the plenary sessions and were in attendance at the break-out sessions.

The OUTLOOK meeting thus provided a wide range of responses to two main questions relating to research and funding of marine biotechnology;

- A profile of Marine Biotechnology in 2030 – research, business and citizens - (Research)
- Marine Biotechnology in 2030 supporting the future marine biotechnology research and innovation landscape - (Funding)

The panel identified a wide range of research gaps, opportunities, barriers, and required actions, in addition to descriptions of the likely MBT landscape in 2030. Organising these responses and taking into account responses delivered in the final plenary session - the likely scenarios for 2030, revealed a number of core themes. Some of the core themes reflected the influence of the global drivers; others implied the existence of other drivers.

DRIVERS

Panel discussions concluded that a wide range of factors that enable and drive European marine biotechnology. When taken in conjunction with the material in the briefing document, they provide the source of potential primary and secondary drivers and help to inform the development of future scenarios. The full list of drivers extracted from the OUTLOOK process and organised according to their source is listed in Table 2 below.

Table 2: Potential drivers of European marine biotechnology

MEGATRENDS	H2020 CHALLENGES	OUTLOOK PANEL
• Changing demographics • Globalisation and future markets • Scarcity of resources • Climate change • Technology and innovation • Global knowledge society • Sharing global responsibility	• Health, Demographic Change and Wellbeing • Food Security, Sustainable Agriculture and Forestry, Marine, Maritime and Inland Water Research and the Bioeconomy • Aquatic living resources and marine research • Agri-food sector for a safe and healthy diet • Bio-based industries • Secure, Clean and Efficient Energy • Climate Action, Environment, Resource Efficiency and Raw Materials • Europe in a changing world - Inclusive, innovative and reflective societies	• Demand for materials/biomass • Climate change • Demographics • Economic performance • Customer and industry perspectives • Societal values/needs • Technological development • Regulatory systems • Environmental policy • Access to resources • Research management

SCENARIO FRAMEWORK

A preliminary analysis of the drivers provided the main or principal drivers – major factors that may shape marine biotechnology research and innovation activity. These drivers provide the reference framework on which to build possible scenarios. The OUTLOOK panel inferred main drivers in highlighting actions/activity that reflect societal values and other actions, all of which, point to the need to ***access resources***. Access to resources is strongly linked to the ***need of society*** for new materials, biomass, exploration, infrastructure etc. The framework provided the basis for four scenarios as outlined below in Figure 2. Each scenario was given a unique name as follows: -

- Voyage of discovery
- Ocean of plenty
- Treading water
- Sea mist

These scenarios do not convey any level of priority or hierarchy. Nor do they attempt to predict the future. Each scenario is identified as equally likely, either alone, or together with elements of the other scenarios as driving marine biotechnology research and innovation activity.

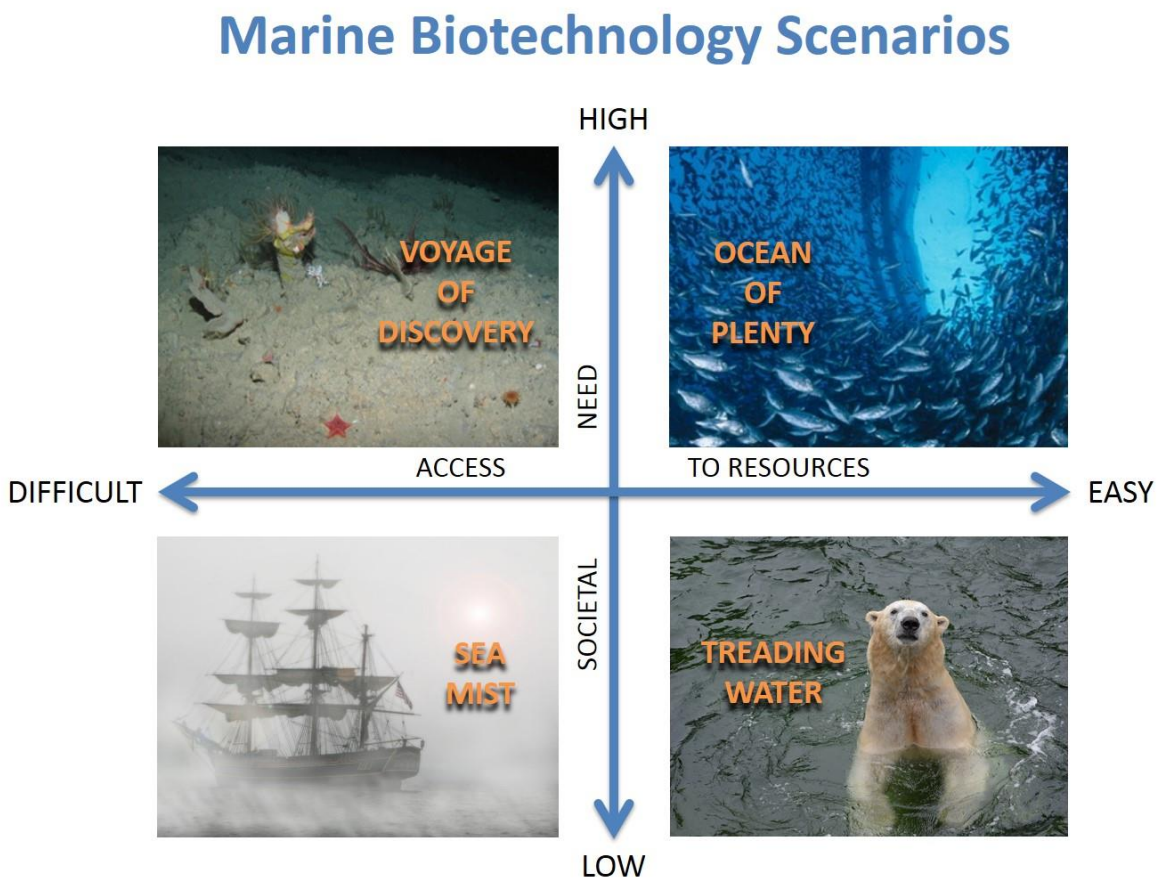


Figure 2: Future scenarios for marine biotechnology. Credits: Marine Institute (Ireland), Research Council Norway (Norway), Pixabay.

KEY CHARACTERISTICS OF THE SCENARIOS

The four scenarios are built upon two key drivers - *access to resources* and *societal need*; and others identified as stimulating or enabling marine biotechnology research, and including drivers, which reflect the emergence and impact of global megatrends. Of the global megatrends, climate change, and changing demographics – particularly increasing global populations and aged populations, scarce resources and the impact of new technologies were identified as relevant to marine biotechnology. Drivers with strong associations not only to marine biotechnology but to RTDI generally include consumer insights, the environment, regulatory and governance systems, in addition to the impact and contribution of new technologies and processes, which influence how research is managed. A summary of the key characteristics of each of the drivers as they relate to each of the scenarios is given in Table 3 below.

Table 3: Characteristics of scenarios

	Voyage of discovery	Ocean of plenty	Treading water	Sea mist
Access to resources	Difficult - involving considerable effort to reach them	Ease of access to traditional marine bio-resources facilitates their use in multiple applications	Few barriers to the use of marine bio-resources, for food use	Any expansion of the role of MBT faces regulatory hurdles
Societal need	Strong demand for novel materials to fill gaps in supply from traditional sources	Solutions to improve health, increase food supply and provide new materials from the marine	MBT is largely limited to supporting the production of marine foods	Focus on traditional uses for marine bio-resources and "natural" products
Marine bio-resources	Expand efforts to search for novel species and materials	Maximise the production and use of known resources	Healthy ecosystems protect the marine resource	Prioritise the use of marine resources for food use
Consumer insights	Positive response to the use of novel materials from marine resources to improve the quality of life	Focus on exploiting available marine resources for new products	Improved living standards and lifestyle choice result in demands for marine products provided the marine ecosystem is protected	Consumer needs can be met by using traditional methods to produce foods from the marine environment
Industry demands	Access and the freedom to harvest new species in order to create high-value materials	Flexible production systems to process blue biomass for multiple applications	Support for new aquaculture and harvesting methods to comply with regulatory requirements	Maximise the productive capacity of the oceans for food use and maintain health status of marine species
Scarcity of resources	Traditional sources of natural products are approaching limits of supply and increasing populations place pressures on food production systems			
Climate change	Is already happening and leading to the introduction of new species and the loss of others as well as changes in the broader marine environment resulting from increased global temperatures.			
Demographics	Growth in global populations continues and the strong emphasis on keeping society health as the share of age persons increases			
Economics	Demand for marine origin products is stimulated by global factors and Europe becomes a focal point for marine biotechnology enabled product production which enhances the			

	performance of the European bioeconomy			
Societal values	Marine biomass is a source of value that can benefit all society and place trust in systems designed to manage its exploitation.		Society remains concerned that traditional uses of marine biomass for food will be overtaken in the search for applications without due regard for the marine environment	
Technological impacts	Enhanced discovery processes are supported by development of the marine biotechnology toolbox and convergence of technologies enable integrated collection and assessment of marine species	Integrated biomass production and processing results in maximum value added to all marine materials	Technological developments target improved culture and harvesting methods and ensuring compliance with regulatory systems	
Regulatory systems and governance	Areas of oceans allocated for exploration/discovery purposes and legal frameworks to support MBT and ownership rights are clarified and established in accordance with ABS principles	Coastal zone management allows for the maximum use of European waters for biomass production	Systems provide for safe marine food production and encourage commercial activity within tightly controlled environmental regulations designed to stimulate enterprise activity	
Environment	The role of MBT in conserving and restoring the environment is an element of the discovery process	Active management of the marine environment ensures environmental sustainability Production systems don't make "waste"	Producers are provided with reliable, real-time information	Environment is more than just environmental stability
Research management	Collaborative, multi-disciplinary research, the encouragement of multiple stakeholder participation and enhanced MBT innovation processes offer Europe a first mover advantage in MBT RTDI			

MARINE BIOTECHNOLOGY SCENARIOS

INTRODUCTION

Each scenario is a reflection of possible situations that may influence or otherwise shape marine biotechnology RTDI. The scenarios, however, include reference to issues that are outside the scope of typical marine biotechnology activity or are only weakly connected to the process. They nonetheless should be noted when identifying research areas. Amongst these are a number of non-scientific issues, that directly influence or are influenced by marine biotechnology RTDI including environmental regulatory systems, research infrastructures, data collection and management, industrial and economic policy, RTDI funding initiatives, consumer awareness and lifestyles, and the management of RTDI. Though an awareness of these "soft" issues is required in building insights to future marine biotechnology RTDI, and indeed possibly to influencing related policy, the primary focus of the future research themes is on scientific and technological research directly enabled by, or involving, biotechnology as applied to marine resources.

SCENARIO 1: VOYAGE OF DISCOVERY

This scenario reflects the high expectations regarding the potential of the enormous biodiversity within the marine environment to contribute to improvements in the lives and life-style of all citizens. New actions to expand the use of marine bio-resources are informed and driven by earlier successes in the sustainable exploitation of marine bio-resources: and their proven contribution in meeting the needs of society for improved health, increased food supply and new advanced materials. All major industry sectors identify the potential to make use of new marine origin and public funds combine with private funds to initiate bioprospecting activity.

The marine environment is identified as a prime and expanding source of biomass and a major factor in the strong performance of Europe's bioeconomy. Societal and economic successes are behind European plans to expand actions designed to discover new marine species and identify opportunities to utilise them in novel applications. Marine exploration, biomass production and bio-refining are strongly linked and supported by sound regulatory and management systems, which aim to create lasting benefits for all citizens. Levels of public awareness of the positive impact and contribution of marine biotechnology are at an all time high and influence the acceptance of the use of this technology.

Supporting the efforts of the specialist firms to harness value from marine biomass is a range of new technologies that are used to target, collect and identify marine species and unlocking their genetic and chemical diversity. Such is the demand for access to novel marine materials; dedicated research-funding measures encourage international collaboration in marine bioprospecting, biodiscovery and the sharing of research infrastructures.

The use of marine origin compounds by the health sector is commonplace and a major driver of demands for expanded ocean bioprospecting from other industry sectors. Once a peripheral research

activity, marine bioprospecting is a mainstream process in the discovery of entirely new marine species from which to obtain novel compounds.

An integral development component in accessing remote regions and assessing the potential of marine organisms to yield beneficial materials is the role of technology from areas typically unconnected to marine biotechnology. Increasingly, new research driven solutions rely on contributions from across the scientific and technological horizon. The same is to be said for the development of new environmental regulations; once seen as a barrier, they now encourage marine biotechnology research activity and the sustainable exploitation of marine biomass. In doing so they stimulated new policy outlooks on accessing and exploiting marine biodiversity.

Across Europe, firms that previously were relatively weakly connected to the marine sector are now linked to each other, and to research organisations, through extensive participation in collaborative research projects. The resulting innovations and technological convergence combined to stimulate the development and application of new solutions that drive and enable the discovery and collection of organisms in previously unexplored regions. Actions as these helped to overcome some of the difficulties and lower the barriers associated with the exploration of hazardous marine environments. There is a network of marine biorepositories, which maintain databases of the genetic, chemical and biochemical properties of marine organisms, extracts and physical samples, making them available to industry and research institutions.

Industry acceptance of the vast opportunity to harness novel materials from marine organisms is high. Continued investment in research infrastructures required to explore the more remote marine territories, coupled with licensing access to ocean regions through the implementation of international agreements have facilitated bioprospecting and encouraged it in areas beyond national jurisdictions.

SCENARIO 2: OCEAN OF PLENTY

Growing, aging populations, health concerns, greater affluence and climate change driven environmental events stimulate the search for novel materials from marine bio-resources, and the processes by which these materials are developed into a diversified range of new products. This scenario reflects the successful targeting and sustainable exploitation of all marine bio-resources in the search for materials.

The marine environment is a prime source of biomass and a major factor in the strong performance of Europe's bioeconomy. Supported by sound regulatory and management systems, the exploitation of marine bioresources creates lasting benefits for all citizens. The focus of the "Ocean of Plenty" reflects the collaboration between marine biotechnology and other scientific and technological disciplines in establishing the sustainable supply of marine biomass. Managed harvesting of marine species and the cultivation of marine biomass at sea and on land combine to provide sustainable sources of biomass. Demand for novel materials drives extensive marine bioprospecting activity.

Aquaculture exists as a reliable and environmentally acceptable food source as well as a "factory" in which marine bio-resources are cultivated as a source of novel materials. The human and animal health sector has built upon the knowledge that marine bio-resources is "home" to a vast array of health beneficial compounds, leading to further increases in biomass production and an expansion of

biorefineries designed to extract value from marine biomass processing systems. Successes in the application of marine biotechnology for food products are behind its acceptance as contributing materials that enable new health solutions. There is a strong preference for marine proteins for food and other uses, since consumers consider their production as more environmentally benign than traditional land based products. Consumers have embraced marine origin foods, thus reducing pressures on more traditional farming systems.

The use of marine origin compounds by the health sector has become commonplace. Not only do these materials provide small molecules with the potential to treat major diseases, they are also a rich source of implantable and other biocompatible materials. Many veterinary compounds are based entirely on marine compounds. Marine derived fish health vaccines protect farmed species from parasites, bacterial infections and viruses. The cosmetics sector is almost entirely dependent on marine origin compounds for use as cosmeceuticals, in addition to passive beauty products. Marine derived enzymes are routinely used in bioprocessing a wide range of health, domestic and industrial products; where properties required by organisms to survive environmental extremes are harnessed to meet the growing need for enhanced product performance. The agricultural sector has become reliant on marine derived treatments for specific crop and animal disease.

Contributions from marine biotechnology have increased our knowledge of the marine environment. As a result, the marine foods sector is better placed to deal with climate related threats to fish health, well-being and production. Climate related threats to food production have been minimised; and knowledge of climate-induced effects that previously threatened the stability has increased. The continued emergence of species previously described negatively as "invasive" are now better understood, offering scope as new sources of marine biomass.

Marine biotechnology research has benefited from contributions from across the scientific and technological horizon. The same applies to the development of new environmental regulations; once seen as a barrier to exploiting marine bio-resources, a range of harmonised policies enable marine biotechnology research activity and the sustainable exploitation of marine biomass.

Public sector research continues to provide new knowledge to all stages of marine biomass exploitation, from cultivation to refining, and supporting the development of novel end-use applications. An increased involvement of the enterprise sector at all stages of the marine biodiscovery and a well-developed biomass production supply chain aids commercialisation processes. A new breed of enterprise activity is targeting the long-term exploitation of marine biomass.

Levels of public awareness of the positive impact and contribution of marine biotechnology are at an all time high. Importantly, there are now reliable estimates of marine biomass of key species within European waters and systems in place that monitor stocks. Remote monitoring is an integral component of data collection on marine biomass. As a result, consumer acceptance of products based on inputs from biotechnology is widespread. Firms that previously were relatively weakly connected are now linked to each other and to research organisations through participation in collaborative research projects. A new generation of research-intensive firms exist: based largely on SMEs that were previously involved in cultivating or harvesting marine biomass or involved in biorefinery processes, they now supply an array of marine biotechnology enabled products to various markets.

SCENARIO 3: TREADING WATER

In this scenario, access to marine bio-resources is largely for food and food related products, and is wholly dependent on maintaining healthy ecosystems. In addition to increased food safety surveillance activity, and robust quality assurance systems, European regulatory authorities reflect and impose society's demand to protect marine ecosystems.

Consumer demands for natural products are increasing as a result of global improvements in living standards, health concerns and other life-style choices that favour the consumption of marine foods over other sources. Improved diets and health care, coupled with better life-style choices created an aging population.

The focus of Europe's regulatory systems is to ensure marine environments can continue to support the traditional harvest and cultivation of marine species for food. Some wild stocks of fish, shellfish and macro algae had been overexploited. The imposition of tighter controls and an improved ecosystems management approach saw wild stocks improve. The production and harvesting of all marine biomass is monitored to ensure compliance with legal and environmental regulations and for firms that are capable of complying with such regulations, entry barriers are low.

Research and development activity supports increase production within tightly constrained environmental management regulations which encourage widespread aquaculture activity. However, concerns amongst European citizens about the use of biotechnology have resulted in a cautious and restricted application of biotechnology in the marine environment.

New technological developments provide accurate data on available biomass and are used in setting harvesting limits for wild and cultured marine biomass and monitoring stocks. Production environments are similarly monitored. Technological developments delivered new production systems to automate the processing of marine biomass, thus reducing supply chains from harvest to end-use and maximising value of all marine origin foods.

There is a strong emphasis on sustainable aquaculture of all species, as a viable alternative to harvesting wild stock. This is supported by technological developments that provide increased output at minimal risk to the environment, assure food safety and protect the welfare of cultured species. Fish and algae farmed in such systems command premium prices compared to imported products.

Marine food processing systems add value to all components of marine biomass. Waste is minimised to the point of being almost invisible, and materials that are not used as "seafood" are used as a source of valuable functional food ingredients and as inputs to the animal feeds and nutrition markets. The priority, however, is on premium human food production where products are sold locally or exported as "fresh". Advanced processing and packaging systems maintain flavour and colour of products and have eliminated any spoilage; allowing packaged seafood to retain the "fresh" label and command premium prices.

Despite the existence of strict environmental regulations, companies operate freely in the marine area. A strong knowledge base exists in marine foods and feed production companies because it is common for these companies to attract the best marine scientist to work for them. Marine research in universities and research institutes generates new biological and ecological knowledge in support of policy/regulation and to aid development of the food industry. Extensive cooperation between

academia and industry occurs and often leads to new research-intensive spin-outs and new business starts in environmental and production services.

SCENARIO 4: SEA MIST

The setting for "sea mist" is an enlarged Europe of 2030 comprising an increasingly affluent society in which citizens have adopted health driven life-style changes. A concept of self-sufficiency has emerged across society. Accompanying this trend is increasing scepticism about the role of science and technology and concerns about the power of industry; both of which are perceived as acting counter to the interests of individuals. The connections between food, health and life-style are well established and there are strong negative perceptions about the impact of the productive sector on the environment, particularly over-exploiting marine natural resources.

There is a high level of awareness of personal health; environmental health and concerns about the rights of individuals are strong. The perception amongst consumers is that "natural" equates to "healthier" food. This led to an increased consumption of marine origin foods and food related products from the sea, coupled with a demand that such products come from sustainable sources. Marine biomass production to targeted towards food use and major effort is directed towards increased production of finfish, shellfish and algae.

The global policy priority is food production. For the marine sector that means attempting to maximise the productive capacity of the oceans. The pressures on global wild stock fisheries from increased demand for marine food variety resulted in the EU fisheries ministers agreeing to impose severe restrictions on the operation of wild catch fisheries in European waters. Such policy shifts were largely acceptable to European citizens and society in general. Despite understanding how the sustainable exploitation of marine bio-resources could contribute to the broader needs of society, there was minimal effort on, or indeed recognition of, exploiting marine bio-resources for other than food, feed and applications that could not be met from land based production.

Ever since negative food, animal health and environmental incidents in the early 21st century the perception of society is that biotechnology, ubiquitous in food production systems, was somehow behind these incidents. Society remains concerned that the marine environment could suffer similar episodes; a view reflected in EU policy perspectives of the role of the oceans in supporting economic growth.

By 2030, aquaculture production has risen sharply in response to market demands for marine foods that could no longer be sourced from wild-catch. Marine foods were recognised as being inherently functional offering health benefits as well as meeting nutritional needs. With this increase in aquaculture output, Europe was challenged to identify new sustainable feedstock and natural based treatments for fish disease and other ailments associated with large-scale aquaculture.

Climate change brought new challenges to the aquaculture sector by way of new pathogens and disease that threatened fish and algal health and production – some as a result of climate change. A new breed of leading veterinary and environmental science and technology-based firms provide real time data on the health status of stock from biological and genetic sensors located within farms, whilst also providing continuous feedback on wider environmental status.

Opportunities for marine biotechnology to support the production of more than food and feed related products exist. However, barriers remain in using marine biotechnology to unlock the value from marine bio-resources. Biopospecting in the marine environment is not supported by policy; nor demanded by industries. Regulations placed restrictions on the use of fish processing discards for human use; these, combined with the societal trust issues concerning bioprocessing for food and health applications limit the full scope of marine biotechnology to contribute other than to support societal needs for food.

RESEARCH NEEDS AND OPPORTUNITIES

INTRODUCTION

The OUTLOOK panel identified specific research challenges that require to be resolved if the broad potential and promise of marine biotechnology is to be realised. These and other findings from the OUTLOOK workshop and scenarios were used to identify thematic research areas for future marine biotechnology RTDI.

The initial research topics suggested by the OUTLOOK panel included research peripheral to marine biotechnology in addition to more specific scientifically or technologically oriented marine and biotechnology research. A number of the topics suggested a role for marine biotechnology to influence European environmental, economic and regional policy. Many of the research topics highlighted the ubiquitous nature of biotechnology and the extent to which marine biotechnology relies on contributions from outside the marine or biotechnology domains; or indeed contributes to research in areas remote from the marine sector. The scenarios also point to the importance of creating an awareness of marine biotechnology, as an influence or contributor to areas and industry sectors remote from the marine sector.

DIRECTIONS FROM THE SCENARIOS

The individual scenarios highlight four quite different possible futures regarding marine biotechnology RTDI. Each of the scenarios raise issues that are common to each; including the sustainable exploitation of marine bio-resources; concerns for the protection and management of the marine environment; the contribution of scientific and technological developments from areas typically unconnected with the marine to marine biotechnology progress; involvement of the enterprise sector; and policy connected to industrial, social and environmental progress, in addition to the requirement for access to research infrastructures and other enablers of marine biotechnology RTDI.

The "Voyage of Discovery" highlights the challenges of exploring marine environments for novel materials amongst the rich biological and environmental diversity of the world's oceans. In doing so, it points to possible areas where marine biotechnology can unlock the chemical and genetic potential of marine organisms and the importance of developing tools and processes to support the activity. Earlier successes in harvesting novel materials from marine species are behind the search for new organisms from remote regions and actions that support an expansion of ocean bioprospecting. It points to the emergence of specialist firms that engage in bioprospecting and of the creation of research networks to commercialise marine origin materials for use in a growing number of novel applications related to health, increased food supply and advanced materials.

Whereas the "Voyage of Discovery" reflects a future need for novel materials from the largely unexplored and often hazardous marine environments, the scenario of the "Ocean of Plenty" draws attention to maximising the exploitation of marine biomass. It describes the use of marine biomass

from cultivated sources in a wide range of areas, all of which, are enabled by biotechnology driven refining processes. Marine biomass feeds the European bioeconomy. There is a wide-level of acceptance throughout society that marine origin materials contribute to meeting the immediate needs of society – and do so in harmony with the environment. Indeed, in this scenario marine biotechnology is identified as having increased our knowledge of marine environments. The "Ocean of Plenty" points to the efficient and sustainable production of marine biomass. Because of the demonstrated successes in sustainably managing biomass production, barriers to entry to marine areas are low.

In sharp contrast to the positive and expansive view of the "Voyage of Discovery" and the "Ocean of Plenty" the other two scenarios reflect concerns about the impact of marine biotechnology on marine environments and its use in areas other than food related production. The "Treading Water" scenario describes a future where marine biotechnology research is essentially static and constrained by concerns about the impact of biotechnology and associated products on the marine environment. Though demand for natural products is increasing and linked to improved lifestyles, European efforts to expand marine biomass production to areas outside food production are seen as threats to what is a stable, sustainable marine foods production system based upon harvesting limits. Biomass production systems are tightly controlled and monitored, however, where producers can demonstrate compliance with regulatory systems and guidelines, entry barriers are low. Contributing to the concept of "sustainability" are processing systems that extract value from all components of marine species. As a result of these successes, new opportunities arise for research collaboration that focuses on the use of marine biotechnology for environmental monitoring and bioprocessing.

The setting for marine biotechnology research in the final scenario, "Sea Mist", is within an affluent European society that is sceptical about role of science and technology in supporting life-style choices. At best there is an indifference to exploiting marine bio-resources for purposes other than food. There are clear indications in this scenario that limits are imposed on marine biomass production to ensure negative environmental events of the past are not repeated. The scenario reflects a global priority - food production - and clearly establishes a role for aquaculture in meeting the demand for marine foods. All marine foods – fish, shell fish and algae are seen as inherently "functional", conveying benefits over and above those associated with basic nutrition. At a time when the core of marine biomass production is directed towards food applications, aquaculture output has spiralled, heralding the development of natural, sustainable feed and disease treatments. New pathogens and other threats to aquaculture emerge from climate change. This stimulates environmental and veterinary research designed to combat such threats. Societal concerns about the marine environment and over exploitation are addressed in environmental policy directives.

THEMATIC RESEARCH AREAS – PLANNING FOR 2030

The panel addressed the high-level research challenges which resulted from an analysis of specific research topics and a review of each scenarios; finally converging them to form thematic areas. The thematic research areas are generic: and are disconnected from specific scenarios, thus indicating research that is required to address possible future marine biotechnology related research and innovation. Table 3 below is a summary distillation of panel feedback arranged according to the

drivers of scenarios. These contributions provide a conceptual link between the scenarios and the thematic research areas.

Table 4: Opportunities, challenges and Marine Biotechnology RTDI gaps

	OPPORTUNITIES	CHALLENGES	RTDI GAPS
Products from marine biomass	• Food and food ingredients and nutraceuticals • High value products not commodity products • Industrial materials • Horticulture products • Pharmaceuticals • Biomaterials • Model organisms • Feed for agriculture • Feed for aquaculture • Proteins, fats and carbohydrates • Fine chemicals • Enzymes • Cosmetics and cosmeceuticals • Culture media	• Meeting the demand for food and feed • Sustainable harvesting and production • Supportive regulations	• Sustainable processing • Understanding of the ecosystem • Modes of action of marine compounds • Knowledge of marine organisms
Sources of marine biomass	• Fish and algae • New species • Processing discards • Marine bacteria and other microorganisms • Novel species discovered and farmed	• Expand aquaculture for fish and algae • Utilise low trophic systems • Off shore aquaculture • Farm the marine environment • Target underutilized species • Fishing and aquaculture discards • Culturing micro-organisms	• Knowledge about low trophic systems • Locating new species • Farming new species • Sustainable harvesting
Processing biomass	• From wild and cultured stocks • MBT as a tool in biomass production • Zero waste from production of biomass • Sustainable systems	• Pilot plants to support up-scaling • Land based production systems • Integrated production and processing systems • Supply chain	• Cope with multiple input streams • Processing of biomass • Use whole species • Multistream processing • Flexible production systems

	•	management • Centralized processing systems • Processing of biomass at sea	• Improved supply chains
Manage the environment	• Active management of the marine environment (role of MBT in conserving and restoring the environment) • Extend coastal zone management to the oceans • Reduce pollution / zero waste • MBT used in monitoring and data collection	• Environmental sustainability • Knowledge of species and impacts of harvesting • Common regulatory systems	• Changes in energy production • Real time systems to monitor the environment • Responding to GMO and other powerful gene tools •
Contribution to society	• Food security / feed people from the seas • Food more than energy • Health issues / keep society healthy • Improved environment • Employment creation and maintenance • Healthy oceans	• Edible biomass • Ocean acidification – affect species • Food vs energy	• Role of MBT in climate change / global warming / • Meet protein demand • Health potential of marine compounds
Increase awareness	• Enhance understanding of MBT • MBT is horizontal and enabling • Highlight where MBT products are on the market • MBT more than marine sector	• Clarify terminology of MBT • Communicate evidence based science and benefits coming from MBT RTDI • Improved communications about MBT • Political leadership required	• Consumer attitudes to MBT • Increased promotion of MBT potential • More case studies to illustrate the impacts of MBT across industry sectors
Economics	• Europe could lead in MBT RTDI • Enhanced management of resources stimulate demand and exploration • Europe as a focal point for marine foods and the use of marine bioresources	• Introduce actions to stimulate demand • Create markets and substitute products in markets • Develop localised production solutions • Incentivise productive use the seas	• Define the real value of the oceans • Cost of not managing the oceans • Economic contribution of MBT to society • How to incentivise exploration and use of marine bioresources

		• Strategic use of taxation • Industry to contribute to research • Food production from seas incentivised	
Societal values	• Resources are the common property of the people • Oceans connect people • Solutions from MBT solve needs of society • Enforce regulatory systems • Oceans support people	• Health of marine bioresources and environment • Acceptability of use and consumption of marine biomass and use of MBT • Environmental justice- can MBT respond and adapts to societal needs and behaviour • Peaceful use of bioresources • Can fishing continue • Acceptance of aquaculture • Visual structures non-threatening to the environment • Acceptance of using the marine and exploiting bioresources	• Societal benefits from MBT • MBT and regulation of marine biomass • Role of MBT in environmental sustainability
Technologies	• Maximum use of molecular methods - toolbox supportive of MBT • Preservation systems • Storage systems • Robotic system for aquaculture • Exploration and collection systems	• Access remote and hostile regions • Access and standard of Biological repositories / databases on discovery • Create innovation hubs for MBT • Exploit knowledge of marine species' genomes • Tech transfer from salmon farming to support other and new species • Novel approaches to biorefining	• Develop the MBT "toolbox" • Enhanced and new discovery processes • Automated exploration and collection of species • Material screens at source • Rapid diagnostics • Exploit enhanced rapid sequencing • Develop metagenomics and other –"omics" • Wide-scale culture of organisms
Regulatory affairs	• Coastal zone management • Apply to the whole water column • NGOs promote MBT	• Ownership rights provide clarity to use of marine biomass • Define a role for NGOs • Is there sufficient	• Clarify legal and regulatory systems relating to MBT activity

	benefits	political will to enforce MBT • Legal framework to support MBT use and innovations/ Regulatory systems support and enable access • Clarification of ownership rights • Areas of oceans allocated for exploration/discovery purposes	
Research management	• Become a first mover in MBT • Encourage and support collaboration • Encourage multiple stakeholder participation • Specialised and integrated courses opens way to future MBT driven innovations	• Speed to market • Define an optimum discovery framework • Expand open innovation • Communication of research results • Reduce tension between public good and private sector • EU commitment to funding • Attract best people / minds to work in MBT • Commercialising IPR • Systems to support MBT RTDI • Visibility of MBT in education systems • Stronger links between industry and academia – win / win	• How to enhance the innovation process • Collaborative, multi-disciplinary research meets needs of MBT • Greater industry and customer involvement

With no shortage of research challenges identified by the panel, they are organised within five thematic areas headed *"Exploration"*; *"Biomass production and processing"*; *"Product development and diversification"*; *"Enabling technologies and infrastructure"* and *"Policy support and stimulation"*. A benefit of adopting this approach is they fit with the "research challenge" philosophy of Horizon 2020, some of which are highlighted in the scenarios e.g. health and well-being; sustainable food production; maximising the benefits of oceans; food, feed and safety; integrated bio-refining; environmental sustainability and technological leadership. Each thematic research area is briefly described below, after which the scope of these areas is further explained. The purpose in providing these insights to research themes, is to give concrete examples of possible research areas to feed directly into the planned ERA-MBT strategic roadmap.

EXPLORATION

Though marine biotechnology has successfully contributed to a wide range of applications, it is yet to mature into an important economically attractive field. The oceans' chemical and biological diversity continues to be attractive to the research and enterprise sectors. A lack of effort in exploring marine environments for new organisms remains a significant barrier in escalating the rate and spread of applications. Relatively little exploration of the extensive marine habitats has taken place. Difficulties of accessing areas outside the shallow coastal zone and the costs of deepwater exploration mean that much of the oceans' depths remain to be discovered.

Despite the absence of a significant pipeline of organisms to screen for potential applications, marine environments continue to yield novel materials on which successful industrial chemicals, pharmaceuticals, food and food ingredients are based. There is much optimism regarding the potential to find novel compounds in species and environments that are yet to be discovered and explored.

Developing marine biotechnology into a mainstream process delivering new applications and products from marine biomass will require exploration activities to be intensified. The often referred to "low-hanging" fruits of new marine biotechnology enabled food ingredients, agricultural and personal care products need to be primed with new organisms and materials. Additionally, there is scope for greater exploration and examination of known sources of bioproducts in order to further refine their chemical and biological profiles. The more challenging long-term and highly lucrative medical and health related applications for marine bioproducts require large-scale exploration activity that is linked to screening platforms designed to assess organisms for chemical novelty.

Government and other agencies have begun to address the concerns of society about the potential negative impact of exploring sensitive environments. A challenge facing the exploration and discovery activity is to employ harvesting and assessment methods that can be deployed without disrupting the marine environments or unbalancing the ecosystem. The development of new exploration platforms and associated identification, sampling and assessment tools to operate in sensitive marine environments is likely to contribute to increased exploration activities.

Scope of research

Research activity under the theme of exploration includes activity that will target, identify and assess marine organisms and systems to support the collection of new organisms in unexplored habitats as well as enable more specific and thorough evaluation of known and available organisms. Increasing the rate of discovery of new bioproducts is essential if the potential for marine biotechnology to contribute to commercialisation activity is to be realised. Preferred research topics include,

- Continuing to target microorganisms deep sea sediments, microbial symbionts from sponges and other organisms; macro and micro algae; bivalves, fish and fish processing discards, and marine fungi as sources of biologically active natural products.
- The discovery of new marine species including microorganisms, as a source of novel materials.
- Exploiting the potential of genetic resources in the discovery process.
- Exploring the chemical and biological diversity of marine organisms.

BIOMASS PRODUCTION AND PROCESSING

Against a backdrop of projected global population growth the demand for biomass is expected to rise dramatically in coming decades. Biomass results from the production of renewable biological resources. Sustainable production and conversion processes are required to produce food, feed and other biobased materials and to stem the use on non-sustainable biomass in supporting economic and social progress. New sources of biomass are required and potential of marine organisms as a viable and sustainable source of biomass is widely recognised.

Two main sources of marine biomass are species that are harvested from the wild, and those that can be cultured either at sea or on the land; a further opportunity for biomass harvesting is to target unused and underutilised marine bio-resources. With many traditional marine fish stocks under threat from being over exploited and concerns that some traditional fishing practices can result in damage to fragile marine ecosystems, alternative biomass production systems are sought. Marine biomass comprises many sources, including whole fish, discards from wild catch or fish processing, aquaculture products, macro-algae (seaweed) – both wild and cultured, micro algae and marine invertebrates, including marine micro-organisms.

Most traditional aquaculture activities have focused on the production of fish for seafood products, though in some regions, macro-algae are grown as a food and food ingredient. Aquaculture production offers scope to culture marine organisms as biomass feedstock for processing to into useable products. Despite the obvious potential offered by aquaculture, there are also concerns in some quarters regarding the development of large-scale aquaculture and the possible impact of such activities on marine ecosystems and the environment.

Creating useable products from marine biomass requires a transformation of the feedstock into a useable format. Typically this is a refining or extraction process that yields intermediate or final products. Biomass processing generally involves several intermediary steps from harvesting to end-use. Long-term goals for improving the performance of the bio-refining process include, shortening the supply chain by integrating the cultivation and processing stages; optimising the production of customised feedstock through controlled cultivation to produce specific compounds; employing multi-stream bio-refining techniques and minimising the production of any waste. Novel biotransformation processes involving the use of marine enzymes to convert biomass appear set to revolutionise the processing of marine biomass.

Scope of research

Principle research challenges in biomass production and processing include increasing the production of marine biomass, establishing the controlled culture of marine biomass; creating efficient transformation and refining processes; reducing the complexity of the supply chain by integrating biomass production and refining, reducing energy demand in processing marine biomass and enhancing the sustainability of the marine biomass conversion by minimising the creation of waste. Specific research topics that contribute to these challenges include,

- Increasing the production of biomass from sustainable marine resources, including exploring the potential to develop off-shore and deep water aquaculture.
- Establishing the controlled culture of marine biomass at sea and on land, including developing techniques to culture marine organisms not currently in culture.

- Creating efficient transformation and refining processes, including concepts of multi-stream inputs and bio refining of mixed biomass feedstock.
- Reducing the complexity of the supply chain by integrating biomass production and refining, reducing energy demand and waste in processing marine biomass.
- Removing bottlenecks in marine biomass transformation and conversion by identifying marine enzymes that can modify the structure of biomass, tailor its chemical and biological properties and reduce the energy demand of transformation.
- Engaging in research to support the expansion of cultured biomass production including measures to minimise and mitigate environmental impacts; addressing waste management; enhance biosecurity and the introduction of new production systems (including breeding/hatchery/genetics/nutrition and health) including the use of molecular methods.

PRODUCT DEVELOPMENT AND DIVERSIFICATION

Recent advances in scientific and technological capabilities in biosciences have led to an increasing number of products based on marine natural products entering the market place. Innovations as these, coupled with the recognition that marine bio-resources represent a largely untapped and under exploited source novel products and processes, fuel the belief that the oceans' offer scope to overcome shortages of novel materials. The successful performance of marine biotechnology in delivering products that contribute to meeting the global challenges of food supply, improved health for all and stimulating the growth and sustainability of industries, is reflected in new policy developments that emphasise the potential of marine biotechnology.

The impact of marine biotechnology in supporting new product and process development is visible in reported successes concerning novel pharmaceuticals; food products, functional ingredients and nutraceuticals; medical and other diagnostic devices; novel industrial materials – composites, biopolymers, enzymes; animal and plant health and feed; personal care and cosmeceuticals; remediation and management of environments; aquaculture – particularly breeding techniques and species development. Principal amongst the sources of materials on which these products are based, are fish and shellfish, sponges and other marine invertebrates, macro-algae, micro-algae, fungi and marine microorganisms.

The bioactive properties of materials isolated from marine organisms include many that are of interest to the health sector. With possible pharmaceutical potential are compounds that indicate anti-tumor, anti-microtubule, anti-proliferative, photoprotective, antibiotic, anti-convulsant and analgesic and anti-infective properties. The inherent biocompatibility of some marine materials make them highly attractive as biomaterials for use in medical devices, for drug delivery or in the repair, replacement or regeneration of tissue. The food industry, already a major user of phycocolloids extracted from algae, recognises marine origin compounds as a source of novel ingredients with functional properties and hence potential application as functional food ingredients for health maintenance and the prevention of chronic diseases.

Other industry sectors are turning to exploit the potential of marine origin materials. Interest from the agriculture and horticulture sector is high resulting from evidence pointing to the beneficial effect of algal extracts in animal and plant health. Similar interests exist in the aquaculture sector,

were there is an increased demand for alternative feedstock to replace traditional fishmeal. The anticipated increased use of the oceans means there are challenges to be met in protecting and managing the marine environment. Some seaweeds act as nutrient pumps, making them attractive in multi-trophic aquaculture where the waste products from one species serves can contribute to the growth of another. At the micro-level, some species of bacteria rely on petroleum oil hydrocarbons as a prime source of their energy; they become abundant in oil contaminated waters and hence offer potential in the remediation of waters following oil-spills.

Scope of research

High expectations exist about the potential of Europe's bioeconomy to contribute to addressing societal challenges and the achievement of economic growth. Marine biotechnology is a cross-cutting and enabling technology that is capable of supporting efforts to bring about greater efficiencies in the optimal and sustainable use of biological resources. The cross-cutting, multidisciplinary nature of marine biotechnology research makes it highly relevant to the efforts of different industry sectors to develop competitive, sustainable, safe and innovative products and processes. Supporting economic progress and helping to meet societal needs is research that will,

- Assess, profile, and maximise the sustainable use of marine bio-resources for applications in human and animal food, as food ingredients, therapeutic compounds, medical devices and biomaterials, cosmetics and cosmeceuticals and as novel industrial materials and processes.
- Further isolate and analyse materials from marine biomass to enhance the understanding their structures and modes of action in human and animal health and food/feed related areas.
- Create novel biosensors based on marine derived materials or marine organisms and explore their use in monitoring the status of marine environments and the safety of marine origin foods.
- Assess the potential of marine origin materials to contribute to improve aquaculture performance including addressing health and disease issues within cultured populations, disease resistance and minimising environmental impacts of production.
- Target new research to identify novel proteins, polysaccharides, lipids, sterols, pigments and antioxidants from marine biomass.
- Investigate the inherent biocompatibility of some marine materials and assess their potential for use in medical devices, for drug delivery or in the repair, replacement or regeneration of tissue.
- Harness the potential of marine organisms to act as experimental models in health related research.

ENABLING TECHNOLOGIES AND INFRASTRUCTURE

Furthering European marine biotechnology research and innovation is reliant on access to facilities, services and resources and the continuous improvement of them. Such infrastructures include research vessels, exploration platforms, laboratories, pilot plant, databases and repositories and an array of increasingly complex analytical tools. The availability of these infrastructures both

encourage and enable marine biotechnology researchers and industry to collaborate, share knowledge and contribute to the development of new products.

Marine biotechnology is an enabling technology possessing considerable potential to contribute to economic growth. Other areas of science and technology, however, largely enable its progress. Without advances in technologies that allow the discovery and mapping of the oceans depths, provide insights to new species, or provide for a greater understanding of the genetic diversity of marine bio-resources and highlight how little is known of the majority of marine species, the impact of marine biotechnology to socio-economic growth would be small. Our understanding of the composition, structure and function of marine organisms and our ability to identify opportunities to use the diversity of marine species as the basis for new bio-based products drive marine biotechnology.

Expanding the search for novel species and increasing the rate of discovery is largely dependent on the availability of tools and systems with which to explore marine environment. The range of different and at times extreme marine environments present many challenges in collecting and assessing marine organisms. Equipment designed to withstand and operate at extreme depths and pressures is required to locate and recover samples. And having retrieved samples, researchers can face practical difficulties. Many marine organisms do not lend themselves to be easily cultured, hence new approaches to culturing are required to bulk-up retrieved samples. The development of new technologies has created an explosion in "omics" sciences, providing for the screening and DNA sequencing of marine species and brought new competencies such as bioinformatics into marine biotechnology. Transfers of technology have also occurred as in the case of the application of metagenomics; first used to explore the terrestrial environment, it now provides knowledge of unculturable marine organisms.

The creation of marine data and sample repositories allows materials collected during research cruises to be archived and made available to the wider research community. Few such repositories exist and efforts to create networks within which materials can be shared are at an early stage.

Scope of research

Realising the future benefits of marine biotechnology requires access to, and continuous investment, in research infrastructures. Research and development networks and collaborations that create the multi-disciplinary research effort required to engage in marine biotechnology and enable technology transfer also need to be encouraged. Marine biotechnology research is largely reliant on contributions from across the scientific and technological horizon to provide the all-essential "tool-kit" necessary in exploring marine environments and developing new marine origin products. Through measures which encourage the convergence of different disciplines, technologies and industry sectors, it will be possible to strengthen marine biotechnology research and innovation. Areas of research required to develop lasting supporting infrastructures includes,

- Develop alternatives to the traditional collection or harvesting of marine organisms, including the development of methods to allow in-situ assessment and screening of marine organisms to increase the rate of the discovery of novel materials.
- The development of predictive tools to improve the identification and targeting of biological "hot-spots" in the oceans.

- Identify and build new competencies and networks to support marine biotechnology research and innovation
- Developing deep-sea equipment for use in habitat mapping and biological resource assessment
- Reducing the costs associated with discovery related activities
- Harnessing knowledge and expertise from other sectors of the bioeconomy to support the rapid development of pilot scale equipment and scale-up of marine biomass refining.
- Assessing the potential for shared and open access marine data and biological repositories

POLICY SUPPORT AND STIMULATION

Marine biotechnology is identified as enabling the conversion of marine biological resources into new products and services and hence creating employment. In doing so, it directly addresses societal challenges and is also influential in the support it provides for other "blue" initiatives and contributions to other industry sectors. The ubiquitous nature of marine biotechnology results in marine biotechnology research and innovation activities being shaped by a wide range of European and international policy instruments. The results generated by marine biotechnology in contributing to European strategic goals can be useful in informing new policy and stimulating new concepts that encourage the commercial exploitation of research results.

Within Europe there are clear policy links across the environment, fisheries and aquaculture, food, health, natural resources and industrial materials, to marine biotechnology. As a result of Europe's Bioeconomy Strategy and the associated Action Plan, a new emphasis on marine biotechnology emerged; this was further reinforced by the "Blue Growth" strategy. These strategies highlight the contribution of marine biotechnology in achieving the goals of the Europe 2020 strategy for smart, sustainable and inclusive growth. Horizon 2020 provides the financial support to implementing these and other strategies designed to allow Europe to become globally competitive in priority areas.

International conventions and treaties seek to establish principles and legal frameworks for managing ocean resources outside territorial waters and hence are relevant to the expansion marine biotechnology research and innovation. The Convention on Biological Diversity is an international agreement for the conservation of biological diversity, the sustainable use of biological components and how benefits arising from the use of genetic resources are to be shared. The United Nations Convention on the Law of the Sea (UNCLOS) is an international treaty concerning the governance of the world's oceans. This wide ranging treaty addresses a number of areas relevant to marine biotechnology addressing the "conservation and management of living resources of the high seas" including aspects of economic rights, pollution of the seas, conservation of marine life, and scientific exploration.

The evolution of international and European marine policy offers marine biotechnology researchers a wealth of new research opportunities. Increased monitoring of the marine environment, biomass stock assessment, harmful algal blooms etc s etc. may require new assessment tools to be developed. Data collected during exploration voyages can contribute new information and baseline data to inform policy. The outputs of marine biotechnology research can support and inform policy development. Drawing the attention of policy makers to the challenges faced by marine

biotechnology in contributing to the development of the bioeconomy, may result in the creation of new policy.

Scope of research

The research areas and opportunities identified in the policy arena do not all require marine biotechnology research actions, other research competencies e.g. in the socio-economic, environmental and international law also contribute to advancing the creation of policy to support marine biotechnology activities.

- Identify ways to expand access to marine bioresources for discovery purposes in European waters and on the high seas
- Develop a comprehensive planned policy research programme to apply the knowledge gained from marine biotechnology research to inform public policy, governance and regulation of marine environment and marine derived products
- Support the introduction of common regulations across member states regarding the harvesting, culture and exploitation of marine biomass
- Establish efficient and responsive regulation and policy development relating to marine bioresources
- Identify mechanisms to attract greater industry participation in marine biotechnology related research
- Identify policy developments to advance marine biomass production and processing capabilities and to reduce barriers to the development of new markets for marine derive products.