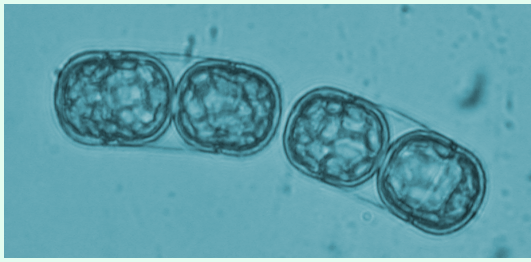

Marine Biotechnology Task Force Report

Marine Institute
Foras na Mara

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EXECUTIVE SUMMARY

Marine biotechnology is a rapidly growing area that is recognised, by policy makers and the enterprise sector, as offering significant potential to develop market opportunities for new products and processes by enabling greater utilisation of marine biological resources. Current research funding activity, supporting efforts to create a sustainable bioeconomy, is likely to lead to a growth in marine biotechnology research and commercial activities. Irish and international financial support for this research is aimed at as yet largely unexplored and underexploited marine resources for use as food, functional foods and nutraceuticals; cosmetics and cosmeceuticals; human and animal health – including pharmaceuticals, biocompatible materials and medical devices; materials technology; environmental bioremediation; and marine model organisms, including the use of marine derived materials in bioprocessing. Research within these areas has resulted in an array of new products and processes which offer benefits to society and support economic growth.

The Marine Institute established a Task Force to advise on the steps required to strengthen Ireland's capability to use marine biotechnology to exploit the value of its extensive marine bioresources. The Task Force, comprising academic and industry members, considered the various national strategies and plans for science, technology, research and economic development, and identified market opportunity areas and Irish marine biotechnology research capabilities. In supporting the work of the Task Force, the Marine Institute completed a number of information-gathering exercises to fill various knowledge gaps identified by the Task Force. Following the preparation of a draft report, the Task Force, with the support of the Marine Institute, held a workshop attended by researchers and companies. This final report of the Task Force takes account of feedback from this workshop in developing its recommendations, which are outlined below.

Specifically, the Task Force recommends the following actions to achieve the ambitious targets set in national policies concerning the utilisation of Ireland's marine bioresources:

- Take steps to ensure Ireland continues to develop the critical infrastructure and research capability required to maintain a leading position in international marine biotechnology research, specifically:

    a) Build on the achievements and progress made in the NutraMara and Beaufort projects by providing funds to create a national virtual Marine Bioresources Research Centre with strong connections to other relevant supporting scientific capabilities and research centres (nationally and internationally). This centre should have the capabilities for species/resource identification; the supply, identification and assessment of bio-actives and modes of action; and pilot-scale biorefining to eliminate bottle-necks in the discovery pipeline.

    b) Focus marine biotechnology research to support food; cosmetics and cosmeceuticals; biomaterials; bioprocessing; and human/animal health and nutrition product and process development.

c) Create, within the Marine Institute, and as an integral component of the virtual Marine Bioresources Research Centre, an Irish marine bioresources bio-bank/repository, initially built around the materials and data collected/generated during the Beaufort and NutraMara projects. This can be enabled by further developing the current Marine Institute laboratory facilities to receive, process, preserve, and curate samples, and by implementing appropriate data management systems to ensure that data relating to species, samples, processing and the distribution of materials are developed and maintained to industry standards. A key function of the repository will be to make data and materials available to the research community and industry, and to enable Irish participation in international "biobanking" initiatives.

- Ensure the continuation of the on-going, short to medium-term, and medium to long-term research priorities identified by the Task Force, aimed at the delivery of "low-hanging fruit" opportunities.

- Enhance the level of understanding of the distribution and availability of marine bioresources. In particular, provide knowledge about the distribution, available biomass and characteristics of commercially relevant species of Ireland's seaweed stock.

- Strengthen the methods used to disseminate knowledge from publicly funded marine biotechnology and bioresources research; thereby increasing the level of understanding of the potential of these areas to contribute to economic progress, to provide industry with insights and access to the results of on-going research activities, and to stimulate greater industry-research interactions, linkages and collaboration.

- Fully integrate Ireland's marine bioresources sector into the wider bioeconomy via initiatives to expand the use of marine bioresources in food, biochemicals and other bio-based materials applications.

- Overcome barriers related to the absence of scale and financial strength, that many SMEs in the marine bioresources sector face in attempting to develop marine biotechnology-enabled products, through the provision of dedicated interventions, support and technical assistance.

- Identify mechanisms to attract and facilitate the participation of expertise from areas identified as supportive of marine biotechnology/bioresources, e.g. ocean observation and mapping, genetics, bioinformatics, chemical synthesis, and process engineering.

- Develop and implement measures whereby all beneficiaries of public research funds that involve the collection of marine biological materials within Irish waters provide samples of all materials collected over the duration of the research grant to a national repository, at their own cost.

CONTENTS

Introduction

Marine biotechnology is a process that can extract value from the chemical and biological diversity of marine organisms and in doing so, apply it to meet societal needs for improved well-being. The early stage sampling of the marine biosphere by Irish, European and other discovery-oriented researchers, in deep waters, identified marine organisms, including bacteria and viruses, with the potential to yield novel compounds with a wide range of applications. Similarly, researchers have identified useful compounds in fish processing discards. These marine derived materials have the potential to provide components for new healthcare, food, environmental and industrial products. As well as new materials, marine biotechnology can provide new tools and processes of relevance to industry.

The inclusion of marine biotechnology as a theme in Sea Change[1] resulted in Ireland being one of the few countries with a strategy for marine biotechnology. Other European countries taking a strategic approach to the exploitation of marine biological resources are Norway and Denmark. Outside of Europe, Japan, South Korea, China and India are widely recognised as the most important players in marine biotechnology, though Korea is the only Asian country with a dedicated strategy for marine biotechnology[2].

The EU recognises the potential of marine biotechnology to create new knowledge, improve industrial competitiveness and spur economic growth. The imperative to exploit living marine resources is prominent in recent EU Policy. Within Blue Growth[3], the strategic goal is to support sustainable growth in the marine and maritime sectors. Marine biotechnology research (so-called Blue Biotechnology) provides a range of novel medical molecules, bio-plastics, enzymes and biocides derived from marine organisms.

European policy also points to the need for food production systems to be more sustainable and recognises the role of marine biotechnology to support food production and processing. The EU view of the bio-based economy includes deriving maximum value in a sustainable manner from all ecosystems. The marine resource includes extensive biodiversity and biological materials (algal, animal and microbial), all of which provide inputs to processing and consumption. Horizon 2020, the current EU research programme, supports this strategy. Under Horizon 2020 *Societal Challenge 2: Food security, sustainable agriculture and forestry, marine and maritime and inland water research and the bioeconomy research* funds will be provided to explore novel marine derived biomolecules and industrial biomaterials and to exploit the potential of marine derived enzymes[4].

The Sea Change strategy, developed by the Marine Institute, recognised that building new research capacity in key areas is fundamental to Ireland's ability to maximise the economic potential of the oceans. Investments by the Marine Institute and other Irish funding agencies continue to enable this capacity-building process, designed to generate the knowledge required to support the creation of high-value marine origin products. Harnessing Our Ocean Wealth[5] and other national strategies[6] recognise the role of marine biotechnology in the delivery of food and health-related products, the creation of novel biomaterials and processes, and to making improvements in environmental health.

1 Sea Change – a Research Knowledge and Innovation Strategy for Ireland 2006-2013. Marine Instutute, Galway 2006.

2 OECD (2013), Marine Biotechnology: Enabling Solutions for Ocean Productivity and Sustainability, OECD Publishing, Paris.

3 http://ec.europa.eu/maritimeaffairs/documentation/publications/documents/blue-growth_en.pdf

4 https://ec.europa.eu/programmes/horizon2020/en/h2020-section/societal-challenges

5 Marine Coordination Group (2012) Harnessing Our Ocean Wealth – An Integrated Marine Plan for Ireland

6 FoodWise 2025 (2014)

The overall objective of Ireland's engagement with marine biotechnology-related research is to enhance the country's international competitiveness through the efficient and sustainable use of marine biological resources. Doing so will support economic growth and job creation by using marine biotechnology to create new bio-based products and processes, protect the marine environment and maintain biodiversity.

Ireland's marine environment is an enormous reservoir of biological and chemical diversity and is the source of novel materials with the capacity to support the development of new products and process applications, ranging from food and food ingredients, to polymers for biomedical applications, and more. Exploiting marine diversity requires a range of scientific and technological skills to understand, harness and develop enterprise opportunities that derive from marine sources.

The global market for marine biotechnology was expected to reach $4.1 billion in 2015 with a potential to reach $4.8 billion by 2020 and $6.4 billion by 2025[7]. Behind this growth is recognition of the potential of marine biotechnology to extract value from marine organisms and deliver materials that are not available from terrestrial sources. There are also reports of growth in the European "blue biotechnology" markets of 6-8% per annum, annual revenue of up to €1 billion and the creation of 10,000 new jobs over 5 years[8].

Marine biotechnology offers many opportunities for "discovery science" and is attractive to a wide range of scientific and technological disciplines. However, exploiting the novelty of marine organisms as a source of new materials is a major challenge for researchers, industry and policy-makers, matched by the challenge of motivating collaboration between biologists, botanists, chemists, microbiologists, pharmacologists and engineers – many with no background in marine science – to work in this exciting research area.

Marine biotechnology is an enabling technology, which contributes to industrial development and enhanced competitiveness and stimulates innovation. Ireland maximised the potential of information and communications technology (ICT) to bring about change in how people live, work and support innovation. Similarly marine biotechnology can play a major part in stimulating innovation in different industry sectors.

7 Smithers Group (2015) The Future of Marine Biotechnology for Industrial Applications to 2025. Available at: http://www.smithersrapra.com/products/market-reports/biomaterials/the-future-of-marine-biotechnology-for-industrial.

8 ECORYS (2014) Report for DG Maritime Affairs and Fisheries, Study in Support of Impact Assessment work on Blue Biotechnology, ECORYS Consultants. Brussels

Marine Biotechnology Task Force Terms of Reference

The Marine Institute established the Marine Biotechnology Task Force to support the continued development of Ireland's capabilities in marine biotechnology research, expand and intensify industry interaction with the research community and advise the Marine Institute in the definition and implementation of activities which will support national and international policies and strategic initiatives to derive economic returns from the exploitation of marine bioresources, as reflected in the EU concept of a diverse and dynamic bio-economy. The Task Force terms of reference were to:

- Create a vision for marine biotechnology RTDI in Ireland and define a path by which to achieve this vision, such that Ireland's marine biotechnology-related policy, research and infrastructure requirements are fully aligned with industrial/economic and commercial opportunities.
- Provide advice on how to develop an Irish marine biotechnology cluster that integrates researchers and industry, and positions Ireland as internationally competitive in securing research funds.
- Advise the Marine Institute on the most appropriate steps to take to strengthen marine biotechnology-related activities in Ireland.
- Provide advice on how best to promote and enhance the awareness of the potential of marine biotechnology across a range of industry sectors.
- Define an industry-oriented event to capture and profile the views and expectations of firms regarding marine biotechnology opportunities.
- Identify mechanisms to strengthen linkages between researchers in life-sciences and researchers working in marine biotechnology-related areas to ensure continued access to new knowledge and essential infrastructure to enhance Ireland's marine biotechnology research capabilities.
- Define a strategic plan, advising on its implementation and assessing its impact.

A Vision for Irish Marine Biotechnology

By 2020, Ireland will have established an international reputation for the creation of new products and processes based on materials isolated from marine biological resources. This will be characterised by research activity that:

- Is relevant to existing and emerging industry sectors, such as to enhance industrial competitiveness, stimulate economic development and sustain marine environments;
- Continues to enable the use of marine origin materials in traditional food- and health-related areas and applications;
- Builds upon existing research collaborations to support the emergence of new foods, food and health, therapeutics, diagnostics, biomaterials and cosmeceutical products and related processes;
- Encourages and supports the engagement of life-sciences research expertise with marine sciences expertise, including access to essential research infrastructures;
- Attracts international funds and positions Irish researchers as leading contributors in advancing marine biotechnology research;
- Commercialises research outputs via licence agreements, through new commercial ventures and spin-outs and, in particular, through linkages with indigenous firms; and
- Positions Ireland firmly within the European Bioeconomy.

What is Marine Biotechnology?

Biotechnology is the process by which biological systems are controlled, manipulated or modified to produce value-added products. The impact of biotechnology is clear in traditional industries such as food and beverages, where it brought about a change in how products are produced and influenced the kind of products that could be produced.

Marine biotechnology is concerned with the discovery and exploitation of biological materials and processes found in marine environments. Developing insights into the genetic and biochemical composition of marine biological resources, deepening our understanding of the environmental and other factors which brought them about, and understanding their position and role within the marine ecosystem are fundamental in realising the economic and societal potential of marine bioresources.

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, including microorganisms, many of which have no terrestrial equivalents, in ways that enable new materials to be created. 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 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.

The process to find marine biological materials to support the development of novel products and processes is termed Marine Biodiscovery. This search for marine organisms and novel materials has stimulated new methods of exploring marine environments and exploiting marine resources. Ireland's well developed biodiscovery process targets coastal and deep-water regions in the search for novel materials and organisms. Results from this work have contributed an array of marine biological samples including macro- and micro-algae, fish and shellfish, marine invertebrates and microorganisms.

Marine Biotechnology – An Alignment of Policy Enterprise Objectives

Marine biotechnology is a rapidly developing area, recognised by policy makers and the enterprise sector as offering significant potential to fill market gaps for new products, as indicated in Blue Growth[9]. EU member states and countries in the Asia-Pacific rim and the Americas[10] have led the challenge of developing marine biotechnology. The European Commission announced a new European Bioeconomy Strategy in 2012. At its core was the twin theme of stimulating research and innovation[11]. The implementation of this strategy, supported by funds from Horizon 2020, stresses the importance of a cross-sectoral and interdisciplinary approach in developing Europe's bioeconomy. The visibility of marine biotechnology projects in the Horizon 2020 work programme highlights its potential and key role in developing the EU bioeconomy. There is a particular emphasis on the role of marine biotechnology research in food security and health, both human and animal, and in bioprocessing. Unlocking the potential of the marine environment, utilising knowledge generated from within cross-cutting marine research, is at the heart of Horizon 2020. This new knowledge contributes to the European Commission Blue Growth initiative, which aims to capture and realise the opportunities to create new high-value food and health products and, in doing so, to deliver long-term growth and jobs in the blue economy.

The availability of research funds to support the development of a sustainable bioeconomy in Europe[12] is leading to a growth in marine biotechnology research and related commercial activity. Irish and international financial support for research is aimed at as yet unexplored and underexploited marine resources for use in food and as food ingredients[13,14,15] (including functional foods and nutraceuticals); cosmetics and cosmeceuticals; marine bio-medicine (including pharmaceuticals discovery and delivery); medical devices; materials technology; environmental bioremediation (using marine-derived materials in bioprocessing); and as marine model organisms. Ireland's Integrated Marine Action Plan – Harnessing Our Ocean Wealth (HOOW)[16] defines the Government's vision, high-level goals and integrated actions across policy, governance and business to enable Ireland's marine potential to be realised. Marine biotechnology research, and maximising the benefits from marine bioresources, fall within the targets and related strategic priorities of HOOW that guide investment in future marine research and innovation activities.

9 European Commission (2012) Blue Growth - opportunities for marine and maritime sustainable growth. 13.9.2012 COM(2012) 494 final. Brussels

10 OECD (2013) Marine Biotechnology: Enabling Solutions for Ocean Productivity and Sustainability, OECD Publishing: Paris.

11 European Commission (2012) Innovating for Sustainable Growth: A Bioeconomy for Europe. 13.2.2012 COM (2012) 60 final. Brussels

12 Biobased Industries Public-Private Partnership (2015) Available at: http://www.bbi-europe.eu/participate/calls-proposals-2015

13 Department of Agriculture Food and the Marine FIRM Programme (2015) Available at: http://www.agriculture.gov.ie/research/2015competitivecallforresearchproposals/

14 Horizon 2020 SC2 Work Programme 2014-2015. Available at: http://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/main/h2020-wp1415-food_en.pdf

15 Horizon 2020 SC2 Work Programme 2016-2017. Available at: http://ec.europa.eu/research/participants/data/ref/h2020/wp/2016_2017/main/h2020-wp1617-food_en.pdf

16 http://www.ouroceanwealth.ie/sites/default/files/sites/default/files/HarnessingOurOceanWealthReport.pdf

The Marine Resource

Marine biotechnology-enabled products result from exploiting the biological diversity of marine environments. A large portion of the surface of the earth (ca. 70%) is covered by the oceans and seas, and more than 80% of all organisms live in aquatic ecosystems[17]. Marine species have evolved to live in various environmental niches; as a result they are a source of novel chemical and bio-chemical diversity.

Ireland's 200,000 hectares of marine territory contains biological and environmental diversity, suggesting the existence of an immense chemical diversity within Irish marine flora and fauna. There are about 450 species of seaweed in Irish waters, a considerable portion of the 600 or so species reliably reported for Britain and Ireland[18]. Ireland's marine fauna includes more than 3,000 species[19] and there are countless bacteria to be found in marine sediment and seawater or living within or on other marine organisms[20].

The Marine Biotechnology Tool Kit

The discovery and retrieval of marine organisms from what can be hostile ocean environments requires specialised research vessels and collection systems. Ireland maintains dedicated research vessels and remotely operated vehicles that can perform surveys and collect species/samples in coastal and ocean territories.

Many analytical techniques are employed to isolate, assess and characterise natural compounds obtained from marine bioresources. Accelerating this discovery process requires support from, and access to, underpinning scientific areas such as 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 required to build biological and genetic libraries. Ireland's expertise in genetics, bioinformatics, an array of "omics" technologies and in the development of assays to assess bioactivity, all contribute to the search for novel compounds and biomaterials from marine organisms.

Moving from laboratory to commercial scale activity requires facilities to develop and demonstrate efficient and sustainable processing systems at each stage of the supply chain. Whilst some companies maintain pilot facilities, the majority of firms face challenges in proving process capabilities in advance of full-scale production. The required infrastructure includes systems to harvest or culture species, to process marine biomass into usable fractions, and ensure production targets are technically and economically feasible. Whilst Ireland has an excellent dairy products pilot facility, no corresponding facility for marine bioresources-based products yet exists.

17 Census of Marine Life Secretariat (2015) Census of Marine Life. Available at: http://www.comlsecretariat.org/research-activities/coml-and-observing-systems/

18 Natural History Museum (2015) About Algae. Available at: http://www.nhm.ac.uk/research-curation/scientific-resources/biodiversity/uk-biodiversity/algaevision/about-algae/index.html

19 Picton BE, Morrow, C. Encyclopedia of Marine Life of Britain and Ireland, National Museums of Northern Ireland. Available at http://www.habitas.org.uk

20 Jensen PR, Fenical W. (1996) Marine bacterial diversity as a resource for novel microbial products. Journal of Industrial Microbiology, November 1996, Volume 17, Issue 5, pp 346-351

Ireland's Emerging Marine Biotechnology Driven Industry

Irish firms already use marine biotechnology to create value from marine bioresources. These firms are an emerging sector of Ireland's wider marine economy and their growth reflects the increased use of marine-derived materials in commercial applications. The current commercial activity within this sector includes fish, shellfish and seaweed culture and harvesting, and the utilisation of these materials as food and food ingredients for human and animal consumption. Some firms process seaweeds for use as industrial materials, plant fertilisers, animal feed and as bioactives for use in health and cosmetic products. Data for this sector show that turnover increased by 5.7% to almost €45 million between 2007 and 2012, with exports accounting for €14.5 million. In 2010, total employment in the sector was approximately 350 persons[21].

Global Markets for Marine Biotechnology

The continued market growth in established and emerging global markets for food-health applications, including functional foods, nutraceuticals, food supplements and other human and animal health related products, stimulates marine biotechnology-related research. This increased level of research in marine bioresources occurs at a time of major advances in marine biotechnology, including the provision of dedicated national and EU research funds, and the generation of a more industry-led research agenda. The ongoing interest from medical, pharmaceutical, aquaculture, nutraceutical and industrial sectors, and the search for novel sources of materials, contributes to the growth in marine biotechnology research activity. Further, there is evidence of new applications in several end-use areas including bioprocessing, environmental remediation and monitoring, cosmetics/cosmeceuticals and agriculture/horticulture.

The global market for marine bioactive substances was expected to have a growth rate of more than 4% during the period 2009 to 2015[22]. The largest and fastest growth end-use segment for marine biotechnology is healthcare/biotechnology. Further insights into the wider markets for products based on marine bioresources include:

- Pharmaceuticals valued at $1.08 trillion in 2011 are forecast to be worth nearly $1.6 trillion by 2020[23].
- The market for marine derived drugs was $4.8 billion in 2011 and was expected to reach $8.6 billion by 2016[24].
- Industrial enzymes valued at $4.2 billion in 2014 are projected to grow at a cumulative annual growth rate (CAGR) of 7% from 2015 to 2020[25].

21 Vega A, Hynes S, O'Toole E. (2015) Ireland's Ocean Economy – Reference Year: 2012, Socio-economic Marine Research Unit. National University of Ireland, Galway

22 Global Industry Analysts (2011) Markets for marine bioactive substances. Quoted in Aquapreneur: http://aquapreneur.com/issue-13/global-marine-biotechnology-market-to-reach-us4-1-billion-by-2015/

23 PWC (2012) ***From vision to decision – Parma 2020*** Available at: http://www.pwc.com/gx/en/pharma-life-sciences/pharma2020/assets/pwc-pharma-success-strategies.pdf

24 BCC Research (2011) Global Markets for Marine-Derived Phramaceuticals. Available at: http://www.bccresearch.com/market-research/pharmaceuticals/marine-derived-pharma-markets-phm101a.html

25 Markets and Markets (2015) Industrial enzymes market report 2015. Available at: http://www.marketsandmarkets.com/PressReleases/industrial-enzymes.asp

- The global functional food market is forecast to reach $54 billion (€43 billion) by 2019, an increase of 25% from 2013[26].
- The global cosmeceuticals market is growing at a CAGR of 9% and is expected to reach $60 billion by 2020[27].
- The global market for biomaterials is expected to reach $130 billion by 2020 and grow at a CAGR of 16%[28].
- The global market for advanced drug delivery systems was valued at $151.3 billion in 2013 and forecast to reach nearly $174 billion in 2018[29].
- The global bone grafts and substitutes market was valued at $2.35 billion in 2014 and is anticipated to expand at a CAGR of 4.5% from 2015 to 2023 to reach $3.48 billion in 2023[30].
- The next generation biologics market, worth $1.5 billion in 2013, is set to continue to grow and reach $30 billion by 2024[31].

The Norwegian Response to Global Opportunities

Norway, like Ireland, prioritised marine biotechnology research and set targets, in the context of a broader national bioeconomy strategy, to use marine biotechnology to exploit underutilised marine bioresources. It identified marine biotechnology as a thematic priority in harnessing the potential of the oceans to stimulate innovation in food and health-related areas. This move was supported by related national strategies in marine genomics, marine bioprospecting, aquaculture and marine foods production. In acknowledging the relevance of marine biotechnology to emerging areas of economic growth, Norway created a marine biotechnology research agenda and established a national marine biomaterials biobank. The interaction between these strategies, coupled with the creation of strong links to industry by research institutions and industry centres, in the context of a long-term vision, aims to ensure that marine biotechnology will drive innovation. The Norwegian strategy recognises the importance of institutions working together on a national basis to harness key research strengths, utilise core infrastructure and build strong research communities, making them attractive partners for international consortia.

26 Leatherhead Food Research (2014) Future Directions for the Global Functional Foods Market. Quoted in Nutraingredients. Available at: http://www.nutraingredients.com/Markets-and-Trends/Functional-foods-market-is-expected-to-grow-25-by-2017-Leatherhead

27 Global Information (2015) Market Research Report – 263147 Global Cosmeceuticals Market Outlook 2020 Available at: http://www.giiresearch.com/report/rnc263147-global-cosmeceuticals-market-outlook.html

28 marketsandmarkets.com (2015) Biomaterials Market by Type of Material - Global Forecast to 2020 Available at: http://www.marketsandmarkets.com/Market-Reports/biomaterials-393.html

29 BCC Research (2014) Advanced Drug Delivery Systems. Quoted in Drug Development and Delivery November/December 2014. Available at: http://www.drug-dev.com/Main/Back-Issues/GLOBAL-DELIVERY-MARKET-Advanced-Drug-Delivery-Syst-804.aspx

30 Transparency Market Research (2015) Bone Grafts and Substitutes Market - Global Industry Analysis, Size, Share, Growth, Trends and Forecast, 2015 – 2023. Available at: http://www.transparencymarketresearch.com/bone-grafts-substitutes-market.html

31 Visiongain (2014) Market Report Next-Generation Biologics: R&D, Industry and Market Quoted in Pharmaceutical Manufacturing June 2014 Available at: http://www.pharmamanufacturing.com/articles/2014/next-gen-biologics-market-worth-30b-by-2024/

Key Growth Areas in Ireland Relevant to Marine Biotechnology

The output from Ireland's marine biotechnology research is relevant to the major growth opportunities in Ireland in health and well-being, human and animal therapeutics, food, biomaterials, and bioprocessing. Ireland's marine biotechnology capacity is increasing and Irish firms are capturing a share of the global market opportunity. Key elements of Ireland's industrial economy that are closely associated with evolving markets for marine biotechnology-based materials include:

- **Food** – The food sector, largely an indigenous sector worth €2.6 billion per annum, provides 163,000 jobs linked to food[32]. It is increasingly research-intensive and driven by biotechnology, possesses an international reputation for dairy origin functional foods and a rapidly developing reputation for marine functional foods research.

- **Pharmaceuticals** – Nine of the world top ten firms have a base in Ireland. In addition, there are some 50 indigenous firms in the sector. Exports from the sector top €50 billion per annum (2013) and the sector employs 25,000[33].

- **Medical devices** – Eight of the world top ten firms have a strong presence in Ireland, as well as some 100 indigenous firms. The sector employs 24,000 in 160 firms and generates an annual revenue of €6 billion[34].

- **Aquaculture** – Comprising a world leading aquaculture MNC and indigenous SMEs, there are 850 licensed operations engaged in producing finfish and shellfish for export markets. The sector employs close to 2,000 and output in 2014 was valued at €115 million[35].

Ireland's seaweed sector was a first mover in exploiting marine biotechnology to support its growth into high-value-added products. Already eight firms, from an estimated 20, are positioned in the functional foods, nutraceuticals, cosmetics and agriculture/horticulture sectors[36]. Annual sales from this new marine-bio-based sector grew rapidly over a three year period to reach an estimated €18 million in 2014[37]. Interest in Ireland's seaweed resource and its utilisation is expanding in line with international trends.

32 Department of Food, Agriculture and the Marine (2015) FoodWise2025 – A 10 year vision for the Irish Agri-food industry. Dublin: DAFM

33 IBEC (2014) Pharma Chemical Ireland sector profile Available at: http://www.pharmachemicalireland.ie/Sectors/PCI/PCI.nsf/vPages/About_us~industry-profile?OpenDocument

34 Enterprise Ireland (2014) Medical Devices Sector profile. Available at: https://www.enterprise-ireland.com/en/Source-a-Product-or-Service-from-Ireland/Sector-and-Company-Directories/Medical-Devices-Sector-Profile.pdf

35 Bord Iascaigh Mhara (2014) BIM Annual Aquaculture Survey. Available at: http://www.bim.ie/media/bim/content/downloads/BIM%20Aquaculture%20Survey%202014.pdf

36 Cybercolloids, ArraMara, Oilean Glas, Marigot, BioAtlantis, Brandon Products, Voya and Irish Seaweed Processors

37 Bord Iascaigh Mhara (2014) Developing seaweed farming to produce a high-value product. Available at: http://www.bim.ie/our-work/projects/developingirishseaweedfarmingforhighvalueproducts/

Target Opportunity Areas

The emergence of a European bioeconomy, focused on the conversion of renewable resources from terrestrial and marine environments into food, feed and related bio-based products, contributes to meeting Europe's grand challenges for the 21st century[38]. Effecting a transition to the bioeconomy is supported by funds for research to discover new applications for the sustainable use of biomaterials. However, there are already active and growing global markets for products, based on or incorporating marine biological materials, as described below.

Therapeutics

Despite a lack of familiarity with the marine environment and a dependency on terrestrial sources for drug biodiscovery, there is an increased awareness of the potential of marine compounds as pharmaceuticals resulting from several notable market successes. Marine biotechnology research led to compounds, extracted from marine organisms, being used in several anti-cancer treatments (Cytostar-U/ViraA sales of $68 million in 2011; Yondelis sales of €76 million in 2014)[39,40]. There are reports of increased commercial attention on the novelty, diversity and drug-like characteristics of the compounds produced by marine organisms. In excess of 20,000 marine-origin natural products have been discovered in the past 20 years, from which some 40 marine natural product based drugs are in various stages of clinical development[41].

Marine origin compounds demonstrate a broad range of bioactive characteristics, including anti-tumour, anti-microtubule, anti-proliferative, photo-protective, antibiotic and anti-infective, in various assays[42]. Results like these make marine natural products an interesting and potentially beneficial source of high-value pharmaceutical ingredients. The diversity of Ireland's untapped marine resource – sponges, bacteria, algae and other species – is a source of novel bioactives with potential for utilisation as pharmaceutical compounds.

38 European Commission (2012) Innovating for Sustainable Growth: A Bioeconomy for Europe, DG Research and Innovation Brussels July 2012

39 Zeltia (2015) Highlights Report at 31st December 2014. Available at: https://www.pharmamar.com/wp-content/uploads/2015/10/INFORME-DICIEMBRE-2014-en1.pdf

40 ABS Initiatve (2014) Sales data according to EvaluatePharma® (UK), a service of Evaluate Ltd. (UK) www.evaluategroup.com. Quoted in Relevance of Marine Bioprospecting for ABS Frameworks, The ABS capacity development initiative. Available at: http://www.abs-initiative.info/fileadmin/media/Knowledge_Center/Pulications/Fact_sheet/Relevance_of_Marine_Bioprospection_in_ABS_context_July_2014.pdf

41 Mayer ASM. (2015) Marine Pharmaceuticals: The Preclinical Pipeline, Midwestern University. Available at: http://marinepharmacology.midwestern.edu/preclinPipeline.htm

42 Martins A, Vieira H, Gaspar H, and Santos S, (2014) Marketed Marine Natural Products in the Pharmaceutical and Cosmeceutical Industries: Tips for Success. Mar Drugs. 2014 Feb; 12(2): 1066–1101

Medical devices

Eighteen of the world top 25 medical devices and diagnostics companies have a manufacturing presence in Ireland. Ireland is now the second largest exporter of medical products in Europe, behind Germany. There are 400 companies in Ireland (of which half are Irish-owned) involved in developing, manufacturing and marketing a diverse range of products and services. This includes disposable plastic and wound care products, precision metal implants (including pacemakers), micro-electronic devices, orthopaedic implants, diagnostics, contact lenses and stents[43]. Ireland's medical device sector is undergoing a transformation, from being predominantly manufacturing based to become more research intensive. This change of focus will result in a collaboration involving a range of partners, including research institutions, clinicians, manufacturing companies and government agencies.

Compared to more traditional sources, marine biomaterials offer the medical device sector access to materials with unique properties including biodegradability, biocompatibility, topography and mechanical strength. Though the commercial use of marine biomaterials remains in its infancy, they offer significant opportunities for use in a range of medical applications. Whilst there is a strong emphasis on the development of biomaterials for human tissue engineering, dental and bone fillers, and in wound healing, current research highlights their use as skin substitutes, adhesives, cartilage replacement and in drug delivery[44]. The sources of these marine biomaterials include macro- and micro-algae, coral, sponges, crustaceans and finfish.

Food products and ingredients

Ireland's food industry is largely an indigenous sector worth €2.6 billion per annum. The sector is increasingly research-intensive and driven by biotechnology. It possesses an international reputation for dairy origin functional foods and a rapidly developing reputation for marine functional foods research[45]. There is a global demand for novel ingredients to support the growth in functional foods. In this fast growing global market, the sales of probiotic and other functional food ingredients are expected to continue to rise. As a result of the market success and beneficial health effects of integrating fish oils into foods, new sources of functional ingredients are being sought. Early results from Irish research to discover novel bioactives from marine biological resources are promising and can enhance the performance of Ireland's food sector in building on the successes of developing niche food ingredient products.

Ireland's marine foods sector is well positioned to create added-value products by more intensive processing of marine bioresources. Opportunities exist to produce food ingredients, nutraceuticals, functional foods, food supplements and cosmeceuticals, and for firms to diversify into new market areas. These opportunities can be realised by the sustainable exploitation of marine biological resources, and by capturing value from within the more traditional processing of marine species for food and non-food use. The potential of the marine as a source of novel compounds for food and other health-related applications continues to attract the interest of key players in policy, research and industry and is highlighted in national strategies.

43 Irish Medical Devices Associoation - About the MEDTECH sector. Available at http://www.imda.ie/Sectors/IMDA/IMDA.nsf/vPages/Medtech_sector~about-the-medtech-sector!OpenDocument

44 Kim Se-Kwon. (2013) Marine Biomaterials Characterisation, Isolation and Applications. CRC Press, Boca Raton.

45 Department of Food, Agriculture and the Marine (2015) FoodWise2025 – A 10 year vision for the Irish Agri-food industry. Dublin: DAFM

Cosmeceuticals

The global market for cosmetics products was $460 billion in 2014 and is set to reach $675 billion by 2020. Within this market cosmeceuticals is the fastest growing segment[46]. These high-value products, which are a relatively recent addition to the cosmetics and personal care markets, provide therapeutic-like benefits to users. The discovery of new ingredients has contributed to the development and growth of cosmeceutical products. There is a strong market demand for organic and natural ingredients in cosmetic and cosmeceutical products. Traditionally, extracts from plants have formed the basis of cosmeceutical products. However, firms from the marine sector are emerging as suppliers to cosmeceutical manufacturers, with some specialist ingredient suppliers providing compounds derived from salmon eggs, micro- and macro-algae, fish skins, and plants found in coastal regions. Responding to the demand from the cosmeceuticals sector for extracts from seaweeds, OceanBasis, a German company, established a seaweed aquaculture activity in the Baltic Sea[47].

Industrial products/processes

The development and use of marine-derived biomaterials remain in its infancy. Scientific capabilities and research infrastructures have developed to the point of being able to be used to explore the marine environment for sources of novel materials. High on the agenda of the industrial biotechnology sector is the search for new materials. Increasingly, firms require customised, individual enzymatic solutions to produce their products. Marine microbes have already demonstrated their potential as a source of novel enzymes used in food, detergent, pharmaceuticals and fine chemicals[48]. An expanding area of interest, to various industry sectors and the bioeconomy, is biopolymers, some of which have already been isolated from marine macro-algae and microorganisms. Many applications exist for these materials including biodegradable plastics, food additives, and medical polymers.

Environmental remediation

Europe's plan to expand the bioeconomy is underpinned by activities in the agriculture, forestry, fisheries and aquaculture, and other bio-based industries. Addressing the challenges of food security, protecting human health, and safeguarding the natural environment are priorities for Europe's bioeconomy. Marine biotechnology can have a substantial impact in protecting and sustaining the marine environment. The scope for marine biotechnology to contribute to the protection and management of the marine environment is likely to expand in line with the increased utilisation of the oceans. There is a role for marine-derived biosensors, biosurfactants, enzymes, and even marine organisms, in monitoring marine environments and facilitating remediation in the aftermath of pollution or other contamination events and in reducing biofouling. The marine is home to a number of bacteria that rely on petroleum oil hydrocarbons as a prime source of their energy. These bacteria become abundant in oil-contaminated waters and therefore offer potential as the basis for products that could be used in the remediation of the marine environment following oil spills[49].

46 Research and Markets (2015) Global Cosmetics Markets. Available at: http://www.researchandmarkets.com/research/f2lvdg/global_cosmetics

47 Organic Monitor (2012) Marine Ingredients in Cosmetics: Sustainability implications. Available at: http://www.organicmonitor.com/r1710.htm

48 Zhang C, Se-Kwon Kim (2010) Research and Application of Marine Microbial Enzymes: Status and Prospects. Mar Drugs. 2010; 8(6): 1920–1934.

49 Zhang C, Se-Kwon Kim (2010) Research and Application of Marine Microbial Enzymes: Status and Prospects. Mar Drugs. 2010; 8(6): 1920–1934.

Agriculture and horticulture

Ireland has a long history in the use of seaweed as an agricultural fertiliser, with large kelp species, available as cast or washed up seaweed, once commonly used for this purpose. Today, raw and milled seaweeds harvested from the wild stock, particularly Ascophyllum Nodosum, continue to be used as fertilisers and soil conditioners[50]. The use of products based on seaweed extracts is common practice in the horticulture sector to increase yield, nutrient uptake and pest resistance in fruit, vegetable and flower crops[51,52]. The use of seaweed as a feed additive is well established in the agriculture sector, stemming from the time when animals reared in coastal regions were allowed to graze on washed-up seaweeds. Coinciding with evidence concerning the beneficial role of seaweed in diets for cattle[53], sheep[54], pigs[55] and horses[56], interest in the use of seaweed in animal nutrition and health is rising. Driven by changes in the regulation of veterinary drugs, new systems of animal production are also required. Research results point to the potential of including seaweed extracts in animal feeds to counter nutritional deficiency, bacterial infection, and low weight-gain, negating the need for growth promoting antibiotics[57]. The aquaculture sector is calling for the development of novel, sustainable feed sources and ingredients for finfish and shellfish production. The inclusion of seaweed or micro-algae extracts in such diets is seen as a possible means of reducing the dependency on the use of fish meal and fish oils in feed, thereby reducing pressures on wild stocks[58].

50 OGT Product Data (2015) Available at: http://ogt.ie/research-ascophyllum/ascophyllum-nodosum/

51 Blunden G (1972) The effects of aqueous seaweed extract as a fertilizer additive. Proc Int Seaweed Symp 7:584–589

52 Sangha JS, Kandasamy S, Khan W, Bahia, NS, Rudra P, Singh RP, Critchley,AT and Prithiviraj B. (2015) λ-Carrageenan Suppresses Tomato Chlorotic Dwarf Viroid (TCDVd) Replication and Symptom Expression in Tomatoes. Mar Drugs. May; 13(5): 2875–2889

53 Rey-Crespo F, López-Alonso M, Miranda M. (2014) The use of seaweed from the Galician coast as a mineral supplement in organic dairy cattle. Animal. Apr;8(4):580-6

54 Hopkins DL, Clayton EH, Lamb TA, van de Ven RJ, Refshauge G, Kerr MJ, Bailes K, Lewandowski P, Ponnampalam EN. (2014) The impact of supplementing lambs with algae on growth, meat traits and oxidative status. Meat Sci. 2014 Oct;98(2):135-41

55 Lynch MB, Sweeney T, Callan JJ, O'Sullivan JT and O'Doherty JV ; (2010) The effect of dietary Laminaria hyperborea derived laminarin and fucoidan on nutrient digestibility, nitrogen utilisation, intestinal microflora and volatile fatty acid concentration in pigs' Journal of the Science of Food and Agriculture, 90 (3):430-437.

56 Moore-Colyer, M (2009) Improving Horses' Diets with Aquacid. Report by The Royal Agricultural College. Cirencester

57 Leonard SG, Sweeney T, Pierce KM, Bahar B, Lynch BP, O'Doherty JV. (2010) The effects of supplementing the diet of the sow with seaweed extracts and fish oil on aspects of gastrointestinal health and performance of the weaned piglet. Livestock Science 134: 1-3: 135-138

58 Gulf Seafood Institute (2014) News Item - International Team of Scientists Exploring Use of Algae for Aquaculture Feedstock. Available at: http://gulfseafoodnews.com/2014/10/19/scientists-exploring-use-of-algae-for-aquaculture-feedstock/

Aquaculture

Population growth, food security, and health and well-being, are the prime drivers of the global food industry. Meeting the future demand for food requires global food production to increase by 70% by 2050[59]. The United Nations Food and Agriculture Organisation (FAO) reports that world consumption of fish averages 19 kg per person/annum and is rising[60], at the same time as global fish stocks are declining as a result of overfishing[61]. Aquaculture is a major opportunity area for marine foods production and for marine biotechnology. Realising the economic, social and regional benefits of aquaculture requires access to knowledge. There is a role for marine biotechnology research to enhance the development of aquaculture by enabling measures that minimise and mitigate environmental impacts, including treatment of waste, supporting new production systems (including breeding/hatchery/genetics), nutrition and health, and biosecurity. The results from research in these areas are relevant to the industry and also support policy development. Ireland's marine biotechnology community is well placed to support the call by the European Aquaculture Technology Platform for the improved management of the biological lifecycle, the development of sustainable feed production, and improved management of aquatic animal health and welfare[62].

Ireland's Strengths in Marine Biotechnology Research

National and international policy and business forecasts highlight the economic contribution of marine biotechnology research to different industry sectors. Significant advances in biological research are occurring, particularly in areas associated with "omics", "systems biology" and synthetic biology. These developments stimulate marine biotechnology research and bring new expertise to work with marine bioresources.

Ireland has an established marine biotechnology research community that is supported by national and international funds. Active university-, research institute- and institute of technology-based projects exist in areas related to biomaterials, bioprocessing, food ingredients and functional foods, drugs and other therapeutic products, animal health and agriculture, aquaculture, medical devices, cosmetics and environmental remediation.

Achieving equilibrium between the exploitation of marine bioresources for commercial purposes and the need to sustain natural stocks is essential to maintain marine biodiversity. This challenge is reflected in the role of marine biotechnology in supporting aquaculture, as well as the increased interest in understanding the largely undiscovered potential of marine organisms to contribute to the development and growth of other industry sectors. Embodied within marine biotechnology research is expertise that can contribute to the realisation of Ireland's economic targets for revenue growth from marine resources and manufacturing activities.

59 FAO (2009) How to feed the world in 2050 – Issues Brief. Available at: http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf

60 FAO (2014) The State of World Fisheries and Aquaculture. Rome: Food and Agriculture Organisation of the United Nations

61 FAO (2009) General situation of world fish stocks United Nations Food and Agriculture Organization (FAO) Available at: http://www.fao.org/newsroom/common/ecg/1000505/en/stocks.pdf

62 EITP (2012) VISION – The Future of European Aquculture. Available at: http://www.eatip.eu/Default.asp?SHORTCUT=92

Research capacity and capabilities

Ireland's marine biotechnology research base includes an estimated 64 permanent academic/research staff working in such areas as microbiology, chemistry, botany, biochemistry, genetics and a range of marine related biological sciences. These Principal Investigators (PIs) currently direct the work of 76 other researchers, 32 at Ph.D. level and 44 Post-Doctoral Fellows, on a range of marine biotechnology projects.

Thematic areas of global opportunity, which correspond to areas of science where Ireland has research expertise, include:

- **Marine Bioactive Compounds and Bioproducts** – a process of discovery, extraction and characterisation of materials from marine macro- and micro-organisms, fish, marine invertebrates, algae, and waste materials stemming from processing of fish, shellfish and algae.

- **Algal Biotechnology** – marine algae have been found to contain quantities of high-value compounds with chemical, food, pharmaceutical, nutraceuticals, cosmetic and agricultural applications. Examples of compounds derived from marine algae are polysaccharides, polyphenols and pigments. Marine algae are known to have a range of environmental applications, including pollution monitoring and bioremediation, in addition to being a source of materials with antioxidant, anti-cancer, antibiotic and other properties.

- **Marine microorganisms** – that may have developed unique metabolic and physiological capabilities with applications in pharmaceuticals, biomaterials and industrial processes.

- **Aquaculture** – the application of molecular biotechnologies, such as "omics" technologies to support aquaculture development (including finfish, shellfish and algae); as food products; and as sources of novel extracts.

- **Marine Molecular Biology** – to characterise, isolate and manipulate the molecular components of cells and organisms from the marine environment. The techniques can be used to identify the presence of a specific organism in a water sample, differentiate between similar looking species and identify genetic structures.

- **Marine Metagenomics** – many marine microbial communities cannot be cultured. Metagenomic-based approaches allow an assessment of the microbial genomes present in marine environments and in doing so enable access to protein-encoding genes from uncultivable marine microorganisms.

- **Biofouling** – investigating the mode of action of bioactive compounds (at genomic, transcriptomic and proteomic levels) against larval settlement; mechanisms of settlement and attachment of micro-organisms, invertebrates, ascidians and macro-algae.

- **"Omics" in Marine Biotechnology** – the development and use of tools and approaches to understand the biochemistry, physiology and phylogeny of marine organisms. Typically, this entails an integrated approach involving sequencing, bioinformatics, transcriptomics, proteomics and phylogenetic analysis, to enable rapid gene discovery and to use these findings in developing novel products from marine organisms.

- **Glycobiology** – characterising marine glycoconjugates for biomedical and biotechnological applications.

- **Biomaterials and Nano-biotechnology** – the discovery and application of natural molecular mechanisms and proteins as found in marine organisms to provide new materials. Typical examples include semi-conductors, bone repair, delivery systems and medical devices.

Recent achievements

Marine Institute grants have supported the development of new research capacity and encouraged scientists from the life sciences, marine biological sciences and the food/nutritional sciences to collaborate on marine biotechnology research leading to the creation of a national programme in Marine Functional Foods and Marine Biodiscovery. Known as NutraMara and the Beaufort Marine Biodiscovery project respectively, this capacity- and capability-building research comprises 25 Ph.D. students, 20 Post-Docs and 21 PIs working across seven institutions. In these projects, which focus on the sustainable exploitation of marine bioresources, Irish researchers target marine organisms as a source of new materials for use in food and health applications. Both projects involve the collection and screening of marine organisms and the generation of research outputs to support the creation of new bioproducts and processes. Outputs include in excess of 150 peer-reviewed publications in addition to presentations, posters, books and book chapters. These projects have also established sample repositories and marine biomaterials databases, which can be made available under licence to other researchers.

Excluding the funds provided to NutraMara and the Beaufort Marine Biodiscovery Project (€12.5m), the PIs involved in these projects secured close to €10 million in additional research grants in 3 years from Enterprise Ireland, Science Foundation Ireland, the Environmental Protection Agency, the Department of Agriculture, Food and the Marine and the EU Framework Programme.

New research partnerships and collaborations within Ireland and Europe have developed from within the NutraMara and Beaufort research projects. As a direct result of their participation in the Beaufort Biodiscovery project, Irish marine biotechnology researchers are participating in three EU research framework projects. Additionally, collaborations between NutraMara and Beaufort PIs resulted in new research grant awards of €4.5 million from the Department of Agriculture, Food and the Marine FIRM Programme.

In addition to the success of public sector researchers in securing European funds for marine biotechnology research, four Irish marine bioresources companies involved in processing seaweeds – Bioatlantis, Cybercolloids, Marigot and Brandon Products – were also successful in securing EU research funds.

Existing research infrastructure

Research infrastructures located at the Marine Institute and in the higher education sector support Ireland's capacity to engage in marine biotechnology research. The availability of ocean-going research vessels equipped with an array of mapping and sample retrieval systems, including remotely operated vehicles, enable researchers to reach the deepest areas of Ireland's marine territories. The collaborative nature of marine biotechnology research in Ireland ensures access to "state of the art" physical, biological and chemical analytical facilities in the higher education institutions. In addition to accessing equipment, researchers draw upon expertise in genomics, molecular methods, systems biology, bioinformatics and other related areas. Major institutional links created within the Beaufort and NutraMara projects enable access to facilities and specialists at research institutes and centres such as the Conway Institute, the Ryan Institute, the Regenerative Medicine Institute, the Environmental Research Institute and the Alimentary Pharmabiotic Centre.

Conditions Required to Develop Irish Marine Biotechnology Research

Exploring marine environments and converting marine biomass into new products and processes relies upon contributions from diverse scientific, technological and engineering disciplines. The many opportunities for marine biotechnology research to contribute to the food, health and biomaterials sectors, demand inputs from multiple scientific and technological sources. Creating the conditions to deliver the promise of Ireland's bioresources sector requires researchers, industry and policy to work closely together. A relatively few generic "imperatives" have to be met to create the environment for Irish marine biotechnology research and innovation to flourish, as outlined below. These include:

- Retaining a focus on innovative scientific and engineering excellence in all aspects of and at all stages in the evolution and application of knowledge;
- Continuing to provide funds for research designed to exploit Ireland's marine resources other than as a source of food;
- Continuing efforts to establish a greater level of visibility and recognition for marine biotechnology in national and EU policy;
- Employing greater precision in the application of research effort towards the "low-hanging fruit" to secure early successes that will contribute to Ireland's ability to be globally competitive in food, health and biomaterials-related business activity;
- Reinforcing the deployment of a sustainable approach to the exploitation of marine bioresources; and
- Providing a focal point for marine biotechnology research as a means of integrating leading and relevant related capabilities to perform internationally competitive research with commercial outcomes.

Marine Biotechnology Research Priorities

Ireland's National Research Prioritisation Exercise (NRPE) stressed the importance of biotechnology for enterprise-driven research in areas such as Sustainable Food Production and Processing (Priority Area I), and Foods for Health (Priority Area H)[63]. Other priority areas – therapeutics, medical devices, processing technologies and novel materials – can also benefit from the results of marine biotechnology research.

A major challenge for marine origin bioproducts is the production of biomass. Providing sufficient biomass, maintaining consistency of the biomass supply chain, and ensuring the security of supply have to be addressed in ways that address concerns for the environment and the concept of sustainable production. Overcoming engineering and environmental challenges, which could otherwise be limiting factors in biomass production and the use of marine bioresources, is critical. Deciding where and how marine biomass is grown requires decision-making processes to take into account the various societal, commercial, scientific and environmental constraints.

The definition of research, and related opportunities to support the growth of Ireland's marine bioresources sector, takes account of current research projects and priorities. This approach builds on the research capabilities and capacity developed in recent years and ensures that current research priorities can be met. In doing so, existing research activities will remain active, as in the case of exploring, assessing and profiling marine bioresources, and the requirement that harvesting and culture of marine bioresources are managed sustainably. Current research priorities will be met by supporting on-going, short- and medium-term research as outlined below.

On-going research

- Engage in research to assess, profile and maximise the sustainable use of marine bioresources for applications in human and animal food, food ingredients, therapeutic compounds, and as novel materials and processes.
- Continue the mapping and assessment of Ireland's marine bioresources.

Short to medium-term research

- Maintain a focus on industry-led research, to enable the maximum use of available biomass, from available and known materials (e.g. seaweeds, processing waste and aquaculture products), in human and animal foods, functional ingredients, cosmeceuticals, agricultural stimulants, and for animal health.
- Direct research activity towards marine organisms as a source of novel enzymes for use in the process industry sector (e.g. food, fine chemicals, consumer products and biopharmaceuticals).

63 Forfas (2012) Research Prioritisation Steering Group Report. Available at https://www.djei.ie/en/Publications/Publication-files/Research-Prioritisation.pdf

- Develop and deploy techniques to culture marine organisms, as an alternative source of biomass, for input to the biodiscovery pipeline, whilst also deploying marine biotechnology to enhance breeding techniques, and as a means of improving the competitiveness of the supply chain.

- Maximise the potential for marine biotechnology to contribute to improved management and decision-making regarding the use of marine biological resources, supporting an ecosystems approach to fisheries management, and investigating the effects of climate change on primary producers, fishery and aquaculture species.

- Investigate the potential for marine biotechnology to make improvements in the production efficiencies of marine origin food products.

Medium to long-term research

- Explore marine bioresources as potential sources of therapeutics, diagnostics and other materials for use in human health applications (e.g. drugs and medical devices).

- Engage in research that will yield novel enzymes from marine bioresources, including research that seeks to deliver new technologies to support the screening, purification and production of marine derived enzymes on an industrial scale.

- Employ novel culturing techniques to create marine biomass with defined chemical and biological characteristics as a sustainable source of high value materials for use in food and health applications.

Future Direction of Ireland's Marine Biotechnology Research

Many national and European policy documents stress the importance of maximising the economic potential of marine biological resources and the contribution of marine bioresources in developing Europe's bioeconomy and Ireland's marine economy. Ireland is a recognised leader in European marine biotechnology research, being one of the first countries to target marine biotechnology towards the exploitation of marine biological resources.

Ireland's flagship marine biotechnology research initiatives – NutraMara and Beaufort Marine Biodiscovery programme – have close links to industry and are engaged in research that is relevant to Ireland's emerging high-growth industry sectors. Together, they continue to attract new research funds, train research talent and collaborate in international research projects. The research outputs from NutraMara and Beaufort are relevant to policy and economic targets set out in Harnessing Our Ocean Wealth and other national strategies and provide a solid foundation on which to build future marine biotechnology research activities. The report of Our Ocean Wealth Development Task Force[64] identified the harvesting and use of Ireland's marine bioresources as a significant component of the marine economy and recommends the creation of a research-driven cluster based on existing capabilities in marine functional foods and biodiscovery, to enhance the utilisation of marine biomass, develop novel processes and add value to marine bioresources.

It is essential to build upon the leadership, scientific excellence, and research achievements of the Principal Investigators involved in NutraMara and Beaufort in developing future marine biotechnology research activity. Adopting a focused, incremental approach for future marine biotechnology research will ensure enhanced research performance and strengthened links between the research and commercial sector. Such an approach requires targeting research towards specific marine bioresources, implementing a prioritised research agenda and the creation of new partnerships. The returns from this approach include the provision of new knowledge and the creation of product and business opportunities, delivering significant economic, societal and environmental progress and developing human capital to support future growth.

The focus of future marine biotechnology research should aim to support the implementation of national and international policy, and enable the achievement of Ireland's strategic objectives to develop a marine economy, via actions that:

- Respond to the **prioritisation of health, food and materials** in the national research agenda and other national strategies, and to the increased global interest in and demand for novel marine compounds;

64 Our Ocean Wealth Development Task Force (2015) Report to the Inter-Departmental Marine Coordination Group. Available at: http://www.ouroceanwealth.ie/sites/default/files/sites/default/files/news/Final%20Our%20Ocean%20Wealth%20Development%20Task%20Force%20Report.pdf

- Maximise the potential to **exploit Ireland's diverse marine natural bioresources** and to utilise waste from marine foods processing, which are a valuable reservoir of biological material;
- Build on **research excellence** in marine bioresources by leveraging benefits from national investments in life sciences/biotechnology;
- Expand the **existing integrated research activities** as a focal point for marine bioresources research, expand **collaboration with industry**, build on global research and commercial linkages, attract international expertise, train researchers and enable diverse industry sectors to create new products and processes; and
- Further develop Ireland's marine research capacity by increasing levels of participation in **international research programmes**.

The definition of priority research areas/opportunities builds on recent successes and reflects Ireland's scientific strengths, the potential of marine biotechnology research to contribute to the growth prospects of existing and emerging industry sectors, and new areas which bolster Ireland's position as a competitive research performer.

Targeting pharmaceuticals, food and health sectors, in addition to building on and enhancing key national industrial/economic development sectors, addresses the existing markets that can benefit from the outputs of marine biotechnology research. The same research competencies, which underpin existing market developments, are relevant to high-growth areas of cosmetics and cosmeceuticals, bioprocessing, nutrition, animal health and environmental products and processing technologies. Target areas for future research include:

- **Marine biomass** – assess and exploit algae, fish, invertebrates and marine bacteria and generate biomass as a source of novel components;
- **Food and health** – functional foods utilising e.g. marine-derived lipids, carbohydrates, polyphenols, proteins, peptides and micronutrients;
- **Biopharmaceuticals** – new compounds and biological activities for human and animal health, cosmetics/cosmeceuticals and bioprocessing;
- **Novel processes** – bioprocessing to produce biochemical components; and
- **Biomedical and environmental applications** – health (medical devices) and environment; control and application of biofouling.

Estimates of the number of marine species, omitting bacteria and archaea, point to the possibility of the existence of between 700,000 to 1,000,000 species, of which about one quarter have to date been described[65]. Such abundance generates significant optimism

65 Appeltans W et al (2012) The Magnitude of Global Marine Species Diversity. Current Biology 22, 2189–2202, December 4.

regarding future supply of novel materials from marine sources. Irish researchers use their extensive knowledge of marine species, acquired as a result of participating in NutraMara, Beaufort and other projects, to guide future research. Taking into account factors such as species knowledge, likely diversity, ease of access, available research infrastructure and relevant expertise, in addition to potential applications, future research targets include:

- **Marine algae** – macro- and micro-algae, particularly Ireland's extensive seaweed resources, that are known to be a novel source of bioactives;
- **Fish and shellfish** – including wild, farmed and processing waste streams, as a source of beneficial lipids, proteins, peptides and amino acids for health and food applications;
- **Marine microorganisms/metagenomes** – that are linked to human/marine life through biogeochemical cycles and ocean food webs, are recognised as having expanding dual roles in bioprocessing and as a source of bioactives; and
- **Marine invertebrates** – deep sea and coastal sponges, cnidarians and ascidians, which are known sources of novel pharmaceutical/therapeutic and other useful compounds.

Recommendations

Harnessing the potential for Ireland to maximise marine biotechnology research in addressing economic and societal challenges and supporting the development of Ireland's marine economy relies on the deployment of scientific expertise in focused areas. Marine biotechnology is an enabling technology in the creation of sustainable food production, food for health, therapeutics and novel materials. It is a technology that cuts across many different industry sectors, including those sectors where Ireland has developed international reputations such as food, medical devices and other health-related areas, including the production of therapeutics. The majority of Ireland's marine biotechnology research takes place in the higher education sector and research institutes where it relies on expertise in marine and related areas in the biological, chemical and physical sciences.

The strategy for marine biotechnology relies on identifying, harnessing and creating linkages between scientific excellence, national priorities and market opportunities. This strategy can be delivered by initiating actions that:

- Direct greater resources towards areas of science that underpin marine biotechnology and industry sectors that are positioned to secure access to market growth opportunities;
- Encourage and support partnerships between researchers and with industry;
- Stimulate the creation of, and maintain, partnerships between research providers in Ireland and with their international counterparts;
- Maximise the use of existing research infrastructure and ensure access to other essential infrastructure;
- Continue to attract new talent and expertise that is complementary to marine biotechnology;
- Maintain a focus on priority areas of marine foods and functional ingredients, and marine origin bioactives for human and animal health applications, novel materials and bioprocessing;
- Support a balanced approach to research that includes targeting so-called "low-hanging fruit", whilst continuing the generation of knowledge to support longer-term opportunities; and
- Encourage leading researchers to collaborate under the auspices of a virtual research centre, thus becoming a focal point for marine biotechnology in Ireland.

Specifically, the Task Force recommends the following actions to achieve the ambitious targets set in national policies concerning the utilisation of Ireland's marine bioresources:

- Take steps to ensure Ireland continues to develop the critical infrastructure and research capability required to maintain a leading position in international marine biotechnology research, specifically:

    a) Build on the achievements and progress made in the NutraMara and Beaufort projects by providing funds to create a national virtual Marine Bioresources Research Centre with strong connections to other relevant supporting scientific capabilities and research centres (nationally and

internationally). This centre should have the capabilities for species/resource identification; the supply, identification and assessment of bio-actives and modes of action; and pilot-scale biorefining to eliminate bottle-necks in the discovery pipeline.

b) Focus marine biotechnology research to support food; cosmetics and cosmeceuticals; biomaterials; bioprocessing; human/animal health and nutrition product and process development.

c) Create, within the Marine Institute, and as an integral component of the virtual Marine Bioresources Research Centre, an Irish marine bioresources bio-bank/repository, initially built around the materials and data collected/generated during the Beaufort and NutraMara projects. This can be enabled by further developing the current Marine Institute laboratory facilities to receive, process, preserve, and curate samples, and by implementing appropriate data management systems to ensure that data relating to species, samples, processing and the distribution of materials are developed and maintained to industry standards. A key function of the repository will be to make data and materials available to the research community and industry, and to enable Irish participation in international "biobanking" initiatives.

- Ensure the continuation of the on-going, short to medium-term, and medium to long-term research priorities identified by the Task Force, aimed at the delivery of "low-hanging fruit" opportunities.

- Enhance the level of understanding of the distribution and availability of marine bioresources. In particular, provide knowledge about the distribution, available biomass and characteristics of commercially relevant species of Ireland's seaweed stock.

- Strengthen the methods used to disseminate knowledge from publicly funded marine biotechnology and bioresources research, thereby increasing the level of understanding of the potential of these areas to contribute to economic progress, to provide industry with insights and access to the results of on-going research activities, and to stimulate greater industry-research interactions, linkages and collaboration.

- Fully integrate Ireland's marine bioresources sector into the wider bioeconomy via initiatives to expand the use of marine bioresources in food, biochemicals and other bio-based materials applications.

- Overcome barriers related to the absence of scale and financial strength, that many SMEs in the marine bioresources sector face in attempting to develop marine biotechnology-enabled products, through the provision of dedicated interventions, support and technical assistance.

- Identify mechanisms to attract and facilitate the participation of expertise from areas identified as supportive of marine biotechnology/bioresources, e.g. ocean observation and mapping, genetics, bioinformatics, chemical synthesis, and process engineering.

- Develop and implement measures whereby all beneficiaries of public research funds that involve the collection of marine biological materials within Irish waters provide samples of all materials collected over the duration of the research grant to a national repository, at their own cost.

ANNEX

Marine Biotechnology Task Force Methodology

The Marine Biotechnology Task Force, with the support of the Marine Institute, designed a process to deliver on the Terms of Reference. This involved the Task Force requesting various information from the Marine Institute about international markets for marine biotechnology based products, Irish and European marine biotechnology related projects and resources involved in these projects. The Task Force invited and met researchers from an ad-hoc group which had presented proposals for a marine bioresources research centre to Science Foundation Ireland.

The Task Force also considered the various national strategies and plans for science, technology, research and economic development. In supporting the work of the Task Force, the Marine Institute completed a number of information gathering exercises to fill knowledge gaps identified by the Task Force. Following the preparation of a draft report, the Task Force, with the support of the Marine Institute, held a workshop attended by researchers and companies. The final report took account of feedback from this workshop.