# Fore*sight* Marine Panel

## Marine Biotechnology Group

# A STUDY INTO THE PROSPECTS FOR MARINE BIOTECHNOLOGY DEVELOPMENT IN THE UNITED KINGDOM

## VOLUME 1 - STRATEGY

**L P M Lloyd-Evans** MA VetMB MRCVS FTOPRA FRSA
**BioBridge Ltd**

This report was commissioned by the

**Fore*sight* Marine Panel**

and financially supported by

**Fore*sight* Marine Panel**
**South West of England Regional Development Agency**
**The Department of Trade & Industry**

**Report: FMP Marine Biotechnology Group – 02 – Volume 1**

**January 2005**

c/o The Institute of Marine Engineering, Science and Technology, 80 Coleman Street. LONDON EC2R 5BJ

Chairman: Mr Frank Mungo
Secretary: Ian Buchanan. Telephone & Fax 01582 715996
email: joyceandian@ibuchanan.fsbusiness.co.uk
Fore*sight* Knowledge Pool: www.foresight.gov.uk
Fore*sight* Marine Web Portal www.marineuk.com

**CONTENTS** **PAGE**

## FIGURES AND TABLES

## ABBREVIATIONS

| | |
|---|---|
| **AIMS** | Australian Institute for Marine Science |
| **BBSRC** | Biotechnology and Biological Sciences Research Council |
| **CCAP** | The Culture Collection of Algae and Protozoa |
| **DEFRA** | Department for Environment, Food and Rural Affairs |
| **DFES** | Department for Education and Skills |
| **DTI** | Department of Trade and Industry |
| **ECF** | Enterprise Capital Fund |
| **ECMB** | European Centre for Marine Biotechnology, Dunstaffnage |
| **EIS** | Enterprise Investment Scheme |
| **EPSRC** | Engineering and Physical Sciences Research Council |
| **ESF** | European Science Foundation |
| **EU** | European Union |
| **FP6** | The EU's Framework Programme 6, of Research and Technology Development |
| **GVA** | Gross Value Added |
| **HEFCE** | Higher Education Funding Council of England |
| **HEI** | Higher Education Institution |
| **HEIF** | Higher Education Innovation Fund |
| **HIE** | Highlands & Islands Enterprise |
| **IACMST** | Inter-Agency Committee on Marine Science and Technology |
| **IP** | Intellectual property |
| **ITI** | Intermediary Technology Institute |
| **KTN, KTP** | Knowledge Transfer Networks and Partnerships |
| **LEC** | SE Local Enterprise Company |
| **M&FMB** | NERC Marine and Freshwater Microbial Biodiversity programme |
| **MBA** | Marine Biological Association of the UK |

| | |
|---|---|
| **MBG** | Fore*sight* Marine Panel - Marine Biotechnology Group |
| **MDIS** | Medical Devices in Scotland |
| **MRC** | Medical Research Council |
| **MSTP** | the proposed Plymouth Marine Science and Technology Park |
| **NERC** | Natural Environment Research Council |
| **NESTA** | National Endowment for Science, Technology and the Arts |
| **NGO** | Non-Governmental Organisation |
| **NHS** | National Health Service |
| **NNFCC** | National Non-Food Crops Centre |
| **OST** | Office of Science and Technology, DTI |
| **PML** | Plymouth Marine Laboratory |
| **PMSP** | Plymouth Marine Sciences Partnership |
| **PSRE** | Public Sector Research Establishment |
| **R&D** | Research & Development |
| **RCUK** | Research Councils UK |
| **RDA** | Regional Development Agency |
| **RSE** | Royal Society of Edinburgh |
| **RVCF** | Regional Venture Capital Fund |
| **SAMS** | Scottish Association for Marine Science |
| **SBRI** | Small Business Research Initiative |
| **SBS** | DTI's Small Business Service |
| **SE** | Scottish Enterprise |
| **SEERAD** | Scottish Executive Environment and Rural Affairs Department |
| **SME** | Small and medium-sized enterprise |
| **SRIF** | Science Research Infrastructure Fund |

## EXECUTIVE SUMMARY

Marine biotechnology in the UK has huge potential for innovative, sustainable development. Marine biotechnology is unlike other areas of biotechnology in that it is defined in terms of its source material, rather than the market it serves. It is best described as the use of marine organisms, at the whole, cell, or molecular level, to provide solutions, thereby benefiting society.

With a global market valued at $2.4 billion in 2002, and a predicted growth rate exceeding 10% per annum over the next three years, there is no doubting that marine biotechnology represents one of the most exciting emerging technology sectors. Marine biotechnology will contribute to nearly every industry sector, from healthcare to bioremediation and from cosmetics to nutraceuticals. The time to invest in the underpinning science, knowledge networks, and public understanding of this major biotechnology field has now arrived.

The UK is well placed to maximise the potential afforded by marine biotechnology due to its maritime heritage with an extensive coastline and easy access to diverse marine habitats. The foundations for a thriving community are in place through a number of geographically dispersed centres of excellence, scientific endeavour in a number of key areas, and a small, but growing, company base.

This report highlights some key areas that would allow this novel sector to mature and flourish:

- A more co-ordinated approach between the research base, entrepreneurial enterprise and the large pharma, biochemical and food multinational companies.
- The integrated use of Research Council funding and the new initiatives offered by Government to promote and encourage innovation.
- Training of researchers and public appreciation of the innovation, sustainability, legal framework[1] of marine biotechnology.

The key issues facing the UK marine biotechnology sector are:

- Developing stable financial investment.
- Creating productive communication between the marine biotechnology community and the private and public sectors.
- Delivering to the industrial sector development leads that are needed and for which they are willing to pay.
- Educating and training the people to make this possible.
- Promoting, marketing and positioning the marine biotechnology sector in a distinctive way.

Through analysis of marine biotechnology prospects in the UK, five areas of activity are identified, with a key recommendation for action attributed to each one:

**Maintaining and developing the R&D base:** The Foresight Marine Panel - Marine Biotechnology Group will consider further, in collaboration with a network of researchers

[1] Owen, D., 2004. A Study into the Legal Framework for Marine Biotechnology Development in the United Kingdom, Report commissioned by the Foresight Marine Panel - Marine Biotechnology Group, sponsored by Defra. ISBN 0 906940 43 5

and companies already established in the sector, the strengthening of one or more centres of excellence in discussion with appropriate bodies (e.g. RCUK - Research Councils UK, DTI and regional development and enterprise agencies).

**Sustaining networks:** By building on existing funded networking activities by the research councils, such as the NERC M&FMB (Marine & Freshwater Microbial Biodiversity) programme, and using new initiatives, for example a Knowledge Transfer Network under the DTI's Technology Programme, to develop a pan-UK approach to marine biotechnology.

**Commercialisation and funding:** The FMP-Marine Biotechnology Group will develop a register of interested venture capitalists, and garner support from biotechnology trade associations (e.g. the BIA), to develop a portfolio of funding opportunities, with the help of the DTI.

These three objectives are underpinned by:

**Scientific Understanding of Marine Biotechnology and Marketing:** New initiatives in public understanding of science will be harnessed to develop readily accessible information that fulfils promotion, PR and marketing objectives.

**Stimulate training and education:** Working with the Funding Councils and Research Councils, the FMP-Marine Biotechnology Group will seek to identify opportunities for modular cross-institution courses in marine biotechnology, including specialist technical skills training.

*By adopting these key recommendations identified in this Marine Biotechnology Prospects Study a focussed strategy for novel and innovative marine biotechnological development in the UK will be realised. "We want the UK to be a key knowledge hub in the global economy, with a reputation not only for world-class scientific and technological discovery but also for turning that knowledge into new and profitable products and services."*

**The Rt Hon Tony Blair, Prime Minister**

The Innovation Report (DTI – December 2003) [2]

***Examples of marine biotechnology applications:***

- The potential for marine natural products as pharmaceuticals was first developed in the 1950s which led to two marine-derived pharmaceuticals that are still in use today. Ara-C is an anti-cancer drug (used against acute myelocytic leukemia and non-Hodgkin's lymphoma) and Ara-A used as an antiviral drug for treating herpes. Both these drugs were derived from natural compounds found in sponges off the coast of Florida. Sponges have provided over 30% of the 5,000 + chemical compounds derived from marine organisms to date.
- More recently, Vent™ DNA polymerase has been isolated from microorganisms living around deep-sea hydrothermal vents. Polymerase Chain Reaction (PCR) is used to amplify very small amounts of DNA or RNA, and forms the basic process

[2] DTI Innovation Report "Competing in the global economy: the innovation challenge" DTI. December 2003 URN 03/1607. Further information available at www.innovation.gov.uk.

behind the gene mapping for the Human Genome Project. PCR requires enzymes that are stable at high temperature, precisely the conditions that the Vent™ DNA microorganism has become adapted to.

- Nutraceuticals, or nutritional supplements, is a major growth area for the large pharma companies. Marine microalgae are known to produce high levels of the fatty acids, docosahexenoic acid (DHA) and arachidonic acid (ARA), both of which are found at high level in breast milk. Because these polyunsaturated fatty acids (PUFAs) have been linked to brain grey matter development, they are regarded as an important nutritional supplement, especially for infants. One such product, developed by Martek Biosciences in the USA, is a market leader.

# 1. INTRODUCTION

## 1.1 This Study

This work was commissioned by the UK Fore*sight* Marine Panel's Marine Biotechnology Group (MBG). It includes information gathered to profile the sector, within UK and in an international context, to provide an overview of market opportunities and to explore strategic options (see **Volume 2** for fuller information). This volume analyses these in a strategic context and includes responses to the interim outcomes from people active in research and commercial development (see **Chapter 5** and **Annex E**). Given the resources available to fund this project, the report cannot be exhaustive. However, the approaches and material collected during the work should form a very useful starting-point for more detailed work during application of a co-ordinated strategy which would allow the UK's marine biosciences and biotechnology community to rise to the challenges presented in the short term and move ahead of other countries in the medium-term.

This study was based on information gathered by BioBridge Ltd during the course of this project from desk research, material to-hand, contacts, and as a result of the workshop/brainstorm on 8 March 2004, a project meeting on 18 May and a project workshop on 7 September 2004. The information has been generated by BioBridge Ltd except where it is directly attributed.

## 1.2 A Definition of Marine Biotechnology

An early question is a definition of marine biotechnology, which is currently origin-defined in a way that may give the impression that it can only take place in or near the sea, or be applied to oceanic activities. Other biotechnology is defined in terms of the end-market applications – food biotech, healthcare biotech, agribiotechnology for example, which tends to make utility to these sectors less of a question. For this project, we chose as our definition of marine biotechnology the following:

**"Marine biotechnology is the use of marine organisms, at the whole, cell, or molecular level, to provide solutions, thereby benefiting society."**

The sector has also been defined[3] in a way that focuses more on the end-uses, as:

**"biotechnology with marine organisms, feeding into aquaculture, marine animal and fish health, marine natural products (including medicines), biofilms, bioremediation, marine ecology and bio-oceanography and other marine products (e.g. enzymes)"**

[3] *UK Marine Industries World Export Market Potential* October 2000, Douglas-Westwood Associates for the Fore*sight* Marine Panel

In this report, the term 'marine biotechnology' is taken to include aspects of marine biology and other marine sciences necessary for the exploitation of living marine resources, but excluding fisheries and conventional aquaculture. For the purposes of the project we have removed vertebrates from the scope. We have also excluded genetically-modified animals, though including in the work some consideration of the use of genetically-improved micro-organisms and processes involving these, as a potential way forward for the constructive use of marine resources.

## 1.3 Vision and Goals

Explicitly stated goals are important for the focus of all players in the sector and are a cornerstone of co-ordinated action. In the case of UK marine biotechnology, developing a mission statement is rather complex, due to the variety of technology streams constituting the output of research and the range of potential end-markets.

Examples might include:

- To be the fastest-growing sector of biotechnology in the UK in terms of project funding and trained researchers
- To be Number 1 in Europe for productive marine biotechnology research by 2010
- To be Number 1 in Europe for exploitation of marine outputs, using marine biotechnology
- To make ECMB (European Centre for Marine Biotechnology) and Plymouth MSTP (Marine Science and Technology Park) the pre-eminent places in Europe for national and international, multi-disciplinary research, and effective technology transfer
- To put UK marine biotechnology on the same level as conventional biotechnology, as a source of new products and processes for other industrial sectors, within 5 years
- By the year 2010, to establish three centres of excellence in marine biotechnology, in Scotland, North of England and South of England
- Of the additional £80 million allocated to the Research Councils in the 2004 spending review, marine biotechnology will aim to secure £4-5 million
- Of the average 5.8% annual growth rate in science funding from 2004 to 2008[4], marine biotechnology should aim to utilise 15-20%
- By 2010, Marine Biotechnology R&D will have contributed 20 new products and spun out 10 new companies in the UK.

Marine bioscience activities should be seen as strategic in a broader context than programmes for monitoring biodiversity that ultimately serve large-scale policies for sustainable management of the seas. Marine biotechnology can contribute to economic development at regional and national level. The costs of establishing marine biotechnology as a productive component of wealth creation do not seem insurmountably high, based on the costs of some of the development instruments

---

[4] *Science & innovation investment framework* 2004-2014 July 2004 HM Treasury, DTI, DfES, page 8

reviewed in **Annex D** and given that the instruments are largely in place that will assist both scientific and economic development.

# 2. PROSPECTS FOR MARINE BIOTECHNOLOGY

## 2.1 Commercial Prospects – Potential Market Size

Marine biotechnology can contribute to marine and non-marine sectors. The overall contribution of marine-related activities to the UK's economy in 1999-2000 has been estimated at £39 billion[5], largely in sectors such as engineering and leisure boating. On a national scale, important marine sectors include fish farming and processing, marine environmental activities and oil/gas extraction. The potential markets for marine biotechnology in these sectors have not been quantified.

An estimate for the eventual contribution of UK marine biotechnology activities to global trade has been provided by a recent report for the Fore*sight* Marine Panel[6]. This estimate of £2.0-2.6 billion is subject to two important *caveats*, that there must be development of added-value products and sufficient financial support to achieve exploitation. The report believes that, in the short-term, the market might evolve from £0.5 billion in 1999 to £1.5 billion by 2004, but does not go in any detail into which sectors might be the most productive and the potential UK contribution to this has not been quantified.[7]

A recent report[8] estimated the 2002 market for marine biotechnology products and processes at $2.4 billion[9], 1/3 in the USA and 2/3 elsewhere, and projected growth of about 6% p.a. 1999-2007, accelerating to 9% p.a. in the 02-07 period.

**TABLE 1: PRODUCTS FROM MARINE BIOTECHNOLOGY - ESTIMATES OF WORLD MARKETS[10]**

| REGION | YEAR AND MARKET £ MILLIONS | | | | | AVERAGE Annual Increase |
|---|---|---|---|---|---|---|
| | 1999 | 2000 | 2001 | 2002 | 2007 | |
| USA | 310 | 350 | 405 | 450 | 570 | 4.7% |
| REST OF WORLD | 745 | 795 | 855 | 920 | 1250 | 6.4% |
| TOTAL | 1055 | 1145 | 1260 | 1370 | 1820 | 5.9% |

This overall estimate includes existing products from marine sources produced using new technologies as well as products such as novel bioadhesives, novel bioactives, for which the risks of failure are quite high.

5 A New Analysis of Marine-Related Activities in the UK Economy with Supporting Science and Technology August 2002, David Pugh & Leonard Skinner for IACMST

6 *UK Marine Industries World Export Market Potential*, D Westwood for the Fore*sight* Marine Panel 2000, ISBN 1-902536-38-X p7

7 UK Marine Industries World Export Market Potential October 2000, Douglas-Westwood Associates for the Foresight Marine Panel

8 Biomaterials from Marine Sources, Business Communications Company Inc Report No. RC-184R, February 2003

9 £1.4 billion at $1.78 = £1.00 (2004 rates), which is used for all subsequent data

10 Source: Business Communications Company 2003

Nevertheless, we believe that the UK's marine biotechnology has a tremendous potential to contribute to the UK, in export terms, as part of the UK's excellent science base and as a driver for regional and national economic development. The overview of market opportunities (here and **Volume 2**) demonstrated that if even a fraction of possibilities for new molecules from the sea could be successfully addressed, there were sufficiently promising markets to make the effort worthwhile to develop and commercialise these marine outputs.

The table below is not intended to indicate the eventual sales of products and raw materials of marine origin, but it demonstrates that there are substantial and significant markets where the characteristics of known products of marine biotechnology can make some contribution to new products.

**TABLE 2: POTENTIALLY ACCESSIBLE MARKET SECTORS FOR UK MARINE BIOTECHNOLOGY**

| Sectors | Value per Annum (circa) |
|---|---|
| cosmetics<br>skin care, sun care, hair care | £47 billion |
| raw materials<br>chondroitin, glucosamine, chitosan | £1.34 billion |
| pharmaceuticals<br>pain-killers, anti-cancer, anti-inflammatories, anti-infectives | £22.5 billion |
| medical devices/biomaterials<br>hydrogels, colloids, cytotoxins | £0.6 - £1.0 billion |
| Tissue engineering | £0.6 - £1.0 billion |
| diagnostics<br>enzymes, biochemicals, chemicals | £1.0 billion |
| Agrochemicals | £17 billion |
| industrial and specialty enzymes | £2.0 billion |
| environmental monitoring and remediation, bioengineering and bioprocess | not estimated |

*Notes: $1.78 = £1.00; estimate for marine materials as components of tissue engineered products given as 5% of total estimate; data relates to various years in period 2000-2003; industrial enzymes est Diversa Corp*

## 2.2 Potential Applications

The range of sectors and potential applications is very wide – the list below in Table 2 is not exhaustive. In addition there is the potential for exploitation of techniques, instrumentation, equipment, engineered products and IT systems that have been developed to assist marine bioscience R&D in other areas. The potential markets for the products of marine biotechnology are expanded upon later in this Chapter. This underlines the need for either strategic focus or the development of a structure (such as a network or platform) that will allow productive discussions between these diverse elements of industry and the academic and institutional research efforts that feed into them, to make best use of the UK's expertise.

## TABLE 3: SECTORS IN WHICH MARINE BIOTECHNOLOGY CAN MAKE A CONTRIBUTION

| SECTOR | POTENTIAL CONTRIBUTIONS |
|---|---|
| FOODS | • new colorants, anti-oxidants, texturing agents, preservatives<br>• enzymes for food processing<br>• edible coatings for foods<br>• functional foods for general healthy lifestyles |
| NUTRACEUTICALS | • specific targets – e.g. heart, joints, osteoporosis<br>• calcium products and other trace elements<br>• anti-oxidants, astaxanthin, carotenoids<br>• marine organisms as probiotics |
| MEDICINE | • pain management products<br>• anti-inflammatory agents<br>• anti-infectives<br>• growth factors<br>• hormones<br>• anti-viral agents<br>• anti-cancer agents |
| HEALTHCARE | • biomaterials, including biopolymers and bioceramics<br>• novel adhesives<br>• biocompatible anti-adhesion coatings for vascular devices<br>• anti-fouling agents for implants and catheters<br>• components of medical devices<br>• encapsulating drug delivery systems |
| COSMETICS | • collagens<br>• anti-oxidants and sunscreens<br>• revitalisers and anti-ageing products |
| RESEARCH TOOLS | • reagents including enzymes<br>• bioactive molecules for growth media<br>• new tools for discovery and testing<br>• libraries of organisms and extracts<br>• model organisms for safety and toxicity tests<br>• marker genes and gene products for molecular biology research |
| PROCESSING TECHNOLOGIES | • extremophile management<br>• improved bioreactor technology<br>• improved purification methods and reagents |
| NEW ENERGY SOURCES | • light-capture<br>• microbial batteries<br>• energy-rich oils<br>• hydrogen-producers |
| AGRICULTURAL | • seed coatings<br>• pesticides, such as toxin from nereid worms or insecticide from sponges<br>• additives, proteins and oils as animal feed ingredients<br>• probiotic organisms in aquaculture<br>• new vaccines and disease control in aquaculture |

### TABLE 3: CONT

| SECTOR | POTENTIAL CONTRIBUTIONS |
|---|---|
| INDUSTRIAL | • novel adhesives<br>• foams for oil industry and other surfactants<br>• non-polluting metal extraction<br>• anti-fouling materials<br>• polymers for general use, thickeners and coatings for textiles and paper<br>• new enzymes for chemical, food, household and other industries<br>• ceramic materials<br>• organisms and wastes as feedstock for biotech and chemical processes<br>• nanotechnological developments |
| FOOD SAFETY | • diagnostics for toxins in seafood<br>• materials for preserving and decontaminating foods and feeds |
| ENVIRONMENT ENHANCEMENT | • pollutant and toxin detection and removal by biocatalysis or digestion<br>• desalination<br>• metal removal and retrieval from soils, water and mining<br>• marine phage viricides for use in microbial films |

It has been possible to identify certain nearer-term targets for UK's marine biotechnology, partly from the recent activities of the Technology Translator within the NERC's M&FMB programme and partly from our broad approach to end-user markets. Realistic early candidates are applications of biofilm knowledge in anti-fouling, applications of marine viruses and new enzymes for biocatalysis. Applying the UK's excellent expertise in marine microbes is also a realistic opportunity, including screening marine actinomycetes for new bioactives. In the longer-term, investigating the potential for marine bioactives in treatment of cell dysfunctions is attractive, since it extends beyond the current preoccupation with cancer to other important therapeutic sectors such as acute and chronic inflammatory diseases, auto-immune diseases and regulating the normal turnover of cells, which would be helpful in supporting skin, intestine and other tissues as they age.

The following section reviews the following sectors and some opportunities within them:

- marine products as raw materials
- food, including health foods and nutraceuticals
- cosmetics
- pharmaceuticals
- medical devices and biomaterials
- regenerative medicine
- diagnostics
- research tools
- agriculture
- industrial uses

- environmental management
- bioengineering

## 2.3 Marine raw materials

Marine products are well-established in many sectors of industrial activity, mainly food, healthcare and agriculture. The three primary groups of product are seaweeds and their constituents, chitin and chitosans from crustacean shells, and vitamins, colorants and lipids from microalgae.

Seaweeds are a source of three very important hydrocolloids used across many of the market sectors that are included in this report – agar, alginates and carrageenan. Agar (agar agar), which contains agarose and agaropectin, is produced by processing of the Rhodophyacean seaweeds *Gelidium sesquipedale*, *Gracilaria* spp. and *Pterocladia*. Alginates, composed of polyguluronate and polymannuronate, are produced by *Laminaria* spp., *Ascophyllum* and *Durvillea*.

Production of high-performance hydrocolloids could be an opportunity for UK companies. NovaMatrix[11], the Norway-based new division of FMC BioPolymers, sells pure sodium alginate at £30/gram, and freeze-dried sterile sodium alginate for pharmaceutical formulations at £190/gram. These alginates are also used in bead encapsulation processes for cells, for research, drug delivery and tissue engineering.

Chitin and chitosans are widely used in healthcare (especially for wound-healing), food, food packaging, healthfoods, flocculation of impurities in liquids, and as antifungals and soil conditioners in agriculture. The higher-volume low-value uses are in agriculture, higher-value in medical devices, and high-volume, high-value in health and food supplements. Because chitosans can be sprayed onto surfaces, they are also used as edible moisture-retaining coatings for fruit, foods and meat, as a means of removing egg yolk from processed egg white, and have been investigated as carcass surface antimicrobial sprays in abattoirs.

In healthcare, high-value uses are obtainable. NovaMatrix produces ultrapure chitosan for intranasal drug delivery and other medical uses from crustacean exoskeleton; sold at £22/gram. The price of glucosamine, an acetylated derivative of chitosan produced from crustacean shells, has risen sharply during 2004 from about £2/Kg to £10/Kg, as a result of US anti-dumping action against shrimp shells from India and an EU ban on Chinese seafood imports. Companies such as Glucomed of Norway are now planning to introduce pharmaceutical-grade glucosamine. Chondroitin is also a health supplement, recommended for skin and joints, which can come from a marine source eg sea cucumbers. Sales of chondroitin, glucosamine and chitosan based products in US alone were £140 million in 1996, rising to £1.35 billion in 2000 as a result of their heavy promotion as nutritional supplements.

The most attractive products from microalgae are surfactants, PUFAs and beta-carotenoids. The current market for surfactants is >4 x $10^6$ tonnes pa. Surfactants from microalgal sources are produced not by the algae themselves but by their

[11] see www.novamatrix.biz

symbiotic micro-organisms, giving rise to the possibility that surfactants can be produced in bioreactors, either by the micro-organisms if culturable or by gene cluster transfer into a conventional fermentation organism. Development work is still required to make the manufacturing process competitive in price with petroleum-based surfactants. SAMS is a UK leader in surfactants from marine sources. Polyunsaturated fatty acids (PUFAs) and pigments have a combined global market of more than several £ billions per year – astaxanthins are worth approx. £115 million per year. These are attractive targets for marine-resource companies and Aquapharm is focusing on a new method of producing astaxanthin.

Marine invertebrates are of interest for their unusual peptides, and one focus is management of pain using derivatives of cone snail neurotoxins. Ziconotide is under development and clinical use by a number of companies under licence from Neurex, a subsidiary of the Irish company élan.

## 2.4 Food, food additives, healthfoods, nutraceuticals, nutritional supplements

Marine products are already well-established in the food sector, particularly gelling and forming agents derived from seaweeds, including agar, alginates and carrageenan. The rise in sales of reduced fat, reduced sugar, reduced calorie and health-image foods opens an added-value opportunity in conventional foods and food additives for the products of marine biotechnology and sustainable production methods of natural marine organisms. Bread baked with fish oil is palatable as long as the oils have been encapsulated, but since fish-origin PUFAs come from marine microbes in the fish diets, such as thraustochytrids, then there should be the potential for using algal oils or fatty acids instead.

There is clearly potential for soya flours to be replaced by marine-origin flours, high in protein and essential fatty acids, provided that controlled and safe production of microalgal biomass and equivalent oxidation stability can be achieved. Marine-origin protein biomass may also provide an alternative to meat. New colorants, anti-oxidants, preservatives and novel flavours from marine sources are possibilities.

Other current trends in food and eating include more snacking and grazing, more convenience foods, organic foods, healthy and vitamin-enriched food for the elderly, added value presentations and character merchandising.

In UK, breakfast cereals and in particular cereal bars are seen as high-growth areas, together estimated at £3.14 billion in 2001 rising to £4.59 billion by 2006, 9% of the total estimated £51 billion market. There should be some potential for use of marine organisms and their extracts as 'healthy lifestyle' and 'natural' ingredients for such foods. These developments seem likelier to be higher-valued, and to move towards functional food and nutraceutical sectors.

Functional foods form one of the most exciting 'clusters' in the food sector, including probiotic products, sports drinks and foods, cholesterol-reducing foods and drinks such as fortified milks, fortified fruit drinks and plant-extract preparations. Vitamin and mineral supplements, which are regarded more as 'health' products than functional or nutraceutical, include products containing ω-3 fatty acids, enzymes, fibre-enriched products and concentrated plant and animal-source products, including algae and fish oils. One successful export from Ireland is calcined seaweed, which is sold by Marigot as an aid in prevention and treatment of osteoporosis. The overall UK market for diet food in 2000 was £5.39 billion, projected to rise to almost £7 billion by 2006[12].

**TABLE 4: MARKET SECTORS FOOD UK, RELEVANT TO PRODUCTS OF MARINE BIOTECHNOLOGY[13]**

| CATEGORY | YEAR & SALES IN £ BILLION ($10^9$) | | | | | COMMENTS |
|---|---|---|---|---|---|---|
| | 1997 | 2001 | 2002 | 2005 EST. | 2006 EST. | |
| FISH AND FISH PRODUCTS | 1.95 | 2.26 | 2.33 | 2.48 | 2.57 | marine products easiest to establish in processed fish sector – as feed additives or as novel foods |
| BREADS, CAKES, CEREALS | 7.71 | 8.96 | 9.33 | 9.97 | 10.18 | marine products as humectants, protein and oil ingredients, whole organisms |
| DAIRY, EGGS, OILS, FATS | 8.03 | 9.89 | 9.14 | 9.66 | 9.76 | marine organisms as probiotics, sources of EFAs |

The single most interesting development in conventional foods is the rise of the functional drink, especially that built on dairy produce and/or probiotic organisms. The major players in this sector are the French company Danone, whose Actimel® sold £285 million world-wide in 2002, from group total sales of £8.1 billion, a good result considering that 90% of the company's turnover in the Asian markets comes from bottled water, and the Japanese company Yakult, 86% of whose £1.0 billion sales come from foods and drinks[14] and whose main Yakult® probiotic drink sells over 600,000 bottles a day in Europe[15].

It seems quite realistic to explore the use of UK marine algae and other organisms and marine extracts as ingredients of such functional foods and drinks. In addition, algae are already available as health foods, including *Dunaliella* and *Spirulina* as sources of antioxidant carotenoids. The US company Martek sells algal fatty acids/oils in baby food formulae. We believe that similar UK-manufactured products from the sea should be able to capitalise on an image of 'organic' and 'natural'.

There may be a rôle for marine-sourced foods and food ingredients in the sectors of fat-reduced and calorie-reduced foods. There is tremendous growth in this market, driven by the realisation that western populations are becoming more obese and developing disorders such as heart disease, arthritis and Type II Diabetes at an earlier age and with greater frequency. Use of marine-origin ingredients can capitalise on existing uses in health and nutritional supplements,

---

12 *Diet and Fat-free foods market assessment 2001*, ed. S Taylor, Key Note (2001), ISBN 1-86111-379-9

13 Source: *The UK Industry Food Market Review*, ed. D Fenn, Key Note Ltd (2002), ISBN 1-84168-394-9

14 *Global Nutraceuticals*, Datamonitor August 2003, Report No 0199-0759

15 *Europe Nutraceuticals*, Datamonitor 2002

of which the commonest are glucosamine from crustacean-shell chitosan, extract of green-lipped mussels from New Zealand and carotenoids such as astaxanthin from microalgal culture.

Astaxanthin is also being marketed as an anti-inflammatory and anti-oxidant, potentially protective against retinal deterioration, diseases caused by inflammation-mediated vascular problems such as heart attacks, providing general support of the immune system and protecting against cancer, all effects apparently observed *in vitro* and in laboratory animals. Mera Pharmaceuticals and Cyanotech of Hawaii are two of the largest producers of microalgal astaxanthin from *Haematococcus*, a freshwater alga, taking advantage of Hawaii's sunshine and warmth to grow the algae in photobioreactors. Microalgal astaxanthin, in pure form for health supplement use, is priced at more than £56,000 per kilogram at retail. It is easy to see why this market could be attractive for UK marine produce.

## 2.5 Cosmetics

Seaweeds already provide many ingredients used in cosmetics formulation. In terms of new product development, the growing interest in cosmetic-based skin protectants and repairing agents and concerns about the impact of sunshine on skin cancers mean that companies active in these sectors are looking for new functional ingredients. The sun care sector has the fastest growth (+7.8% compared with +4.8% overall).

**Table 5: Markets for cosmetics[16]**

| Category | 2003 sales in £ billion ($10^9$) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Total | US | Japan | France | Germany | UK | Italy |
| All cosmetics | 113 | 25 | 12 | 6.8 | 6.5 | 5.7 | 4.8 |
| Of which: | | - | - | - | - | - | - |
| Hair care | 23 | | | | | | |
| Skin care | 22 | | | | | | |
| Colour cosmetics | 16 | | | | | | |
| Fragrances | 12 | | | | | | |
| Bath & shower | 11.5 | | | | | | |
| Oral hygiene | 11 | | | | | | |
| Men's grooming | 9.6 | | | | | | |
| Deodorants | 5.3 | | | | | | |
| Sun care | 2.4 | | | | | | |
| Baby care | 2.0 | | | | | | |
| Depilatories | 1.7 | | | | | | |

Marine-origin sodium alginates and chitosans can be used as micro-encapsulators for active ingredients and, in the case of chitosan, provide some stabilising and anti-oxidant activities that are of interest in new-wave cosmeceuticals. The prospects are also very interesting, in the context of this project, for bioactives as cosmetic and cosmeceutical ingredients. In addition to novel bioactives from

16 Source: The Hellenic Centre for Investment, see www.elke.gr

marine invertebrates and their associated microbes, there are anti-oxidants and other compounds from seaweeds including fucoidans and carrageenan.

Examples of successfully-commercialised products which would bear analysis by any UK initiative in this area include

- a liposome-based product from the US company AGI Dermatics, containing a photolyase from the blue-green alga *Anacystis nidulans*
- pseudopterosin, the anti-inflammatory extracted from the sea-fan *Pseudopterogorgia elisabethae*, the active ingredient in Estée Lauder skin lotions, which has generated more than $2 million royalties for the University of California
- the St Malo, France, company Laboratoires Codif's algal extracts from microalgae and from seaweeds, including Dermochlorella®, an extract of *Chlorella vulgaris*, which is claimed to be a skin restorative and Phycosaccharides® from *Laminaria digitata*, a skin penetrant used to treat acne and ageing skin.

## 2.6 Pharmaceuticals

In 1999, 20 of the best-selling non-protein human medicines were natural products or natural product-derived (synthetic or semi-synthetic analogues). Combined sales of these products exceeded £9 billion[17]. According to the authors of the report on Antarctic bioprospecting[18], annual sales derived from traditional knowledge using genetic resources are £1.7 billion for the cosmetics and personal care industry, £11 billion for the botanical medicine sector and £42 billion for the pharmaceutical industry. More than 60 percent of the cancer drugs approved by the US Food and Drug Administration are of natural origin or are modelled on natural products.

The human pharmaceutical products market is enormous, which is what makes it appear so attractive. The Top 20 companies sold over £160 billion-worth of products in 2001[19]. The single largest sector of medicines is antibacterials, estimated at £14 billion, projected to grow to £18 billion by 2010[20]. The market for non-antibiotic prescription medicines is dominated by three sectors – depression, hypertension and cancer. The world market for antidepressants is estimated at £9.5 billion in 2002, with five products each contributing more than £0.6 billion in sales[21]. The anti-cancer sector, estimated at £8.5 billion, includes several products that are, in fact, 'blockbusters' – Taxol® is one such, with sales of more than £0.6 billion a year. In the cancer sector, almost half of the products are cytotoxic agents, the class into which almost all anti-cancer marine bioactives fall. The value of the active ingredients used in all medicines is estimated at £28 billion, 15-16% of the total price of the product.

---

[17] A Harvey, *Drug Discovery Today*, Vol 5 No 7 July 2000

[18] The International Regime for Bioprospecting, Existing Policies and Emerging Issues for Antarctica UNU/IAS Report August 2003

[19] see http://www.abpi.org.uk/statistics

[20] figure extracted from Quorex web-site www.quorex.com

[21] *Antidepressants world prescription drug markets*, Theta Report #1234 December 2003, PJB Publications

Accordingly these would seem a naturally-attractive target for marine biotechnology and, indeed, there has been a drive to develop bioactives from marine sources since the adenine arabinosides A and C (Ara-A and Ara-C) were isolated from *Cryptotethya crypta*, a Caribbean sponge, in the 1960s and discovered to be potent antiviral and anticancer agents, respectively.

There are other sectors of the pharmaceutical and biopharmaceutical markets that could also be targets for marine-derived products and might prove to be less problematic than anti-cancer agents:

**TABLE 6: ESTIMATES FOR SOME MEDICAL SECTORS**

| CONDITION | MARKET | COMMENTS |
|---|---|---|
| Sepsis | £3 billion worth of healthcare costs per annum in the US alone[22] | products that can more effectively disarm the organisms causing this, or reduce and reverse the effects of endotoxic shock and multiple organ failure, will be very attractive |
| Neuropathic pain | in US alone, £240m in 2002 to £450m by 2007 and £700m by 2012)[23] | ziconotide, derived from the cone shell venom, is already being developed |
| NSAID market | world-wide of about £5.5 billion | anti-inflammatories and mild-to-moderate pain |
| Urinary incontinence | £600m, 5-8%, of a total £11b market | projection for drug-related management is >£6 billion by 2008; marine-origin products could be active in both these sectors, as bioactives with neuromuscular effect or as biomaterials for implantable devices |
| Gout | over £1.1 billion each year | Lytone Enterprise, a Taiwanese company launching a product made from deep-sea fish peptides |

On the research front, and underlying the pathogenesis of several important groups of human and animal diseases, are two fundamental cellular and cell-cell signalling processes – apoptosis and angiogenesis. Molecules that control these processes have tremendous potential in the management of cancers, chronic inflammatory diseases, and our responses to body damage and acute infections (see **Tables 7 and 8**). It is clear already that many bioactives obtained from marine invertebrates and/or symbiotic or free-living microbes have a strong effect on cells and, doubtless, they will also have effects on apoptosis and angiogenesis. There is also potential for exploitation of signalling molecules in control of bacterial diseases, particularly quorum or consensus molecules, which regulate the interaction between micro-organisms in monospecific populations and in the communities that make up biofilms and other assemblages. This is an area of activity in which the UK is especially expert, partly as a result of the NERC's Marine Biofouling Thematic Programme MBTP.

---

[22] see www.theratase.com web-site

[23] *Neuropathic Pain*, EP Publications, WWMR Inc, www.WWMR.com

### TABLE 7: ESTIMATE OF WORLD MARKET FOR APOPTOSIS-RELATED PRODUCTS, 1999-2005[24]

| PRODUCT TYPE | SALES (£ MILLIONS) | |
|---|---|---|
| | 1999 | 2005 |
| Diagnostics and laboratory research materials | 6 | 11 |
| Cancer | 0 | 200 |
| CNS and neurodegenerative | 0 | 45 |
| Cardiovascular | 0 | 45 |
| **Total** | 6 | 301 |

### TABLE 8: MARKET ESTIMATES FOR ANGIOGENESIS MODULATORS[25]

| SECTOR | YEAR AND ESTIMATED SALES IN £ MILLION | | | | |
|---|---|---|---|---|---|
| | 2003 | 2004 | 2005 | 2006 | 2007 |
| **Total** of which: | 56 | 65 | 320 | 690 | 1670 |
| anti-cancer (AI) | - | - | 70 | 170 | 450 |
| dermatology (AI) | - | - | 56 | 135 | 365 |
| cardiovascular disease (AS) | - | - | 56 | 110 | 280 |
| diseases of back of the eye (AI) | - | - | 35 | 67 | 225 |
| arthritis (immune and damage) (AI) | - | - | 28 | 100 | 210 |
| advanced wound care (AS) | 56 | 65 | 80 | 105 | 140 |

*notes: AI = angiogenesis inhibitors, AS = angiogenesis stimulators*

One challenge facing marine biologists and chemists is that too many novel compounds can be isolated from marine invertebrates, marine symbionts and free-living micro-organisms. Producing a list of all those mentioned in the literature would be a monumental task and is beyond the scope of this project, though a partial list is given in **Volume 2**. It is, however, a suitable target for a web database, especially if information on sources, activities, commercial developers, development stages and holders of Intellectual Property Rights is included. There are disparate databases available but nothing that truly co-ordinates all information.

More importantly, investigating all these molecules is impossible. Finally, a successful bioactive is one that reaches the patient, not one that has exciting new activity *in vitro*. These challenges are drivers for new developments in isolation, identification, characterisation and biological screening techniques. Biological screening in particular moves away from the chemist's arena of the structure-activity relationship as a predictor of therapeutic potential to actual testing against

---

[24] *Apoptosis: New Growth Opportunities*, Business Communications Co Inc July 2000

[25] Theta Report *Angiogenesis Inhibitors & Stimulators* PJB Publications 2002

targets in a high throughput screen. This also drives cross-discipline developments on novel sensors that can be incorporated into autonomous underwater vehicles (AUVs) and other sampling equipment.

## 2.7 Medical devices and biomaterials

The medical device market is the most definable of those that use biomaterials and is worth >£20 billion. Device sales in Europe are estimated at approximately £7 billion, about a third of these sales coming from biomaterials-dependent devices; this proportion probably holds true in US as well. The majority of these are based on biocompatible synthetic polymers but there is an established sector of natural biomaterials (see **Table 9**). Those hydrocolloids and materials of marine origin include chitosans and chitins from crustacean exoskeletons, alginates and other seaweed hydrocolloids and coral-origin bone replacers. There is some additional potential for marine-origin collagens and gelatins to replace mammalian material, as a result of concerns over disease transmissions and improvements in economy of waste-processing.

**TABLE 9: NATURAL BIOMATERIALS – FORECASTS FOR USE**[26]

| SECTOR | GLOBAL ESTIMATES £ MILLION |
|---|---|
| Hyaluronic acid & collagen (cosmetic use) | 170 – USA only |
| Hyaluronic acid for viscosupplementation (use in joints, eyes) | 85 – world, growth 40% pa |
| Collagen injectable and other device uses (cosmetic and woundcare) | 225 – world |
| Gelatin (cosmetic, device component) | 900 – world |
| Hydrocolloids and hydrogels (woundcare) | 450 – growth 8% pa US, 12% pa EU |

Biomaterials for wound-care and general surgical use, and devices for cardiovascular and orthopaedic use are the sectors of interest for products from marine biotechnology. Drug delivery can also provide a market for marine-derived ingredients as carriers and formulation components. An added area of opportunity might come from increased understanding of cell-to-cell signalling, to aid integration of devices by the patient.

[26] *Biomaterials Strategy for Scotland*, BioBridge 2003 for SE Edinburgh & Lothian

**TABLE 10: BROAD ESTIMATES FOR MEDICAL DEVICE END-USE SECTORS OF INTEREST, GLOBAL DATA**[27]

| SECTOR | ESTIMATED ANNUAL SALES £ MILLION | | | | | |
|---|---|---|---|---|---|---|
| | 1999 | 2000 | 2001 | 2002 | 2003 | GROWTH RATE |
| Devices | 16,300 | 18,250 | 21,250 | 22,250 | 24,700 | 8-14% |
| Medical coatings[28] | | 5,600 | 6,000 | 7,500 | 10,000 | |
| Drug delivery | 3,000 | 3,500 | 4,000 | 5,000 | 6,000 | >16% |
| Tissue engineering[29] | 10 | 11 | 12 | 16 | 20 | >16% |
| Approx. total | 20,000 | 27,000 | 31,000 | 35,000 | 41,000 | |

One important and growing sector of medical devices is cardiovascular stents, tubes that can replace blood vessels in the heart, main blood vessel trunks or peripheral blood system when they have been narrowed by disease. The US sales for conventional stents of £2.3 billion (2001) are projected to rise to £2.5 billion if drug-eluting and other controlled-cytotoxicity stents are successful, and will also enlarge the £0.9 billion for other angioplasty products used in peripheral blood vessels. Marine-origin bioactives and biomaterials may certainly have a role to play in coating devices and implants with a biocompatible and lubricated surface and in cutting down unwanted cellular reactions.

In the orthopaedic area, there is research activity to produce usable scaffolds from ordered combinations of chitosan fibres, which can be turned into woven, knitted or non-woven fabrics, and bone-like minerals such as coral-derived hydroxyapatite[30]. Chitosan-based materials are already used as sutures and wound dressings. The potential here seems, however, to be rather low compared with other applications such as wound-healing, largely because of current reliance on metals for orthopaedic devices and the slow uptake of bone replacers containing bioactives such as bone growth factors. This will change in the next 5 years, so that any marine-origin bioactive that is likely to have a cell- or healing-stimulating effect should be screened for its osteogenic or chondrogenic activity.

In drug delivery (see **Table 11**), rapidly-growing product sectors include inhalable therapies, gene therapy delivery using polymeric carriers (of which chitosan is one) and mucoadhesive products (mouth, gastrointestinal tract, anogenital). Delivery systems in which marine-derived materials could be used as carriers include quick-dissolve tablets and no-water tablets; mucosal bioadhesives; hydrocolloid osmotic devices; lipid-encapsulation technologies; nasal and pulmonary delivery of microparticles.

---

27 PJB New Developments in Biomaterials 2000

28 *Advanced Polymers for Medical Applications* Kalorama Information KLI 513 899 2002, ISBN 1-56241-781-9

29 virtually all bioartificial skin products

30 Japanese and European work described in Baran Et, Tuzlakoglu K *et al.*, *Multichannel mould processing of 3D structures from microporous coralline hydroxyapatite granules …* J Mater. Sci.: Mater. Med. 15 (2004) 161-165

**TABLE 11: MARKET BREAKDOWN FOR DRUG DELIVERY SYSTEMS – US ONLY**[31]

| SECTOR | MARKET SIZE £ BILLION | | | GROWTH RATE |
|---|---|---|---|---|
| | 1990 | 2000 | 2005 | 2000-05 |
| Oral administration (prolonged release, delayed release, mucoadhesive) | 1.4 | 12 | 19 | 8.6% |
| Parenteral (injectables, targeted therapies, liposomes) | 3 | 7 | 11 | 9.5% |
| Inhalation products | 1.6 | 4.2 | 6.4 | 9.0% |
| Transdermal & implantable | 0.08 | 0.8 | 1.5 | 13.3% |
| **Total** | 6 | 24 | 29 | 9.1% |

## 2.8 Cell therapy, tissue engineering, regenerative medicine

Marine biotechnology and marine biological research could make a strong contribution to these areas of frontier medicine, through marine-origin materials (see **Table 12**) – bioactives, adhesives, anti-adhesives, biocompatible colloids, nanostructures, porous materials – as well as increasing our knowledge about how cells and substrates interact and how cell-cell signalling can be affected. Beneficial discoveries in this area might include molecules that alter the ability of cancer cells to coalesce and multiply, or metastasise.

Targets for marine biotechnology might be cell-activating and cell-maintaining agents or biocompatible cell carriers that help to localise cell implants, thus providing opportunities for marine-derived actives as well as biomaterials.

**TABLE 12: POTENTIAL ROLES FOR MARINE-DERIVED PRODUCTS IN TISSUE ENGINEERING**

| POTENTIAL ROLES FOR MARINE-DERIVED PRODUCTS |
|---|
| protectants for cells (oils, chitins, polysaccharides) |
| scaffolds for cells (chitins, diatoms) |
| stem-cell differentiator (bioactives) |

Because of differences in definition and what is included, estimates of the future global tissue regeneration market vary from £1.2 billion through £2.6 billion[32], even to £45 billion, the latter including wound healing and chronic non-healing ulcers as well as products replacing existing devices for soft and hard tissue repair.

31 Drug Delivery Systems, Freedonia Reports 2001

32 *New Development in Biomaterials*, a Clinica report, PJB Publications 2000

**TABLE 13: MARKET BREAKDOWN FOR POTENTIAL TISSUE ENGINEERED TARGETS**[33]

| PRODUCT SECTOR | MARKET SIZE (£ BILLION) | YEAR |
|---|---|---|
| Venous stasis ulcers | **1.6** | 2002 |
| Pressure ulcers | **1.1** | 2002 |
| Diabetic foot ulcers | **0.8** | 2002 |
| Other soft tissue/surgical | **2.1** | |
| of which acute wounds | 1.1 | |
| anti-adhesions | 0.6 | |
| Heart valves | **0.6** | 2008 |
| | **0.4** | 2000 |
| of which: | | |
| tissue valves | 0.15 | |
| pericardial-flap valves | 0.06 | |
| mechanical valves | 0.2 | |
| Cardiovascular stents | **1.2** | 2001 |
| | **1.7** | ? |
| Of which: | | |
| small-diameter | 0.2 | |
| Regeneration of bone, cartilage, tendon, ligaments | **8.5** | |

One activity that could enhance opportunities for marine biotechnologists and researchers of marine-origin materials in the UK would be to interact with the increasing numbers of centres for regenerative medicine and tissue engineering in Europe, to explore opportunities for co-developments.

## 2.9 Diagnostics

The global *in vitro* diagnostics market was estimated to reach £13 billion by 2003[34], and revenues of European biotechnology-based diagnostics companies reached about € 1 billion in 2002[35].

[33] *Biomaterials Strategy for Scotland*, BioBridge 2003 for SE Edinburgh & Lothian

[34] New Trends in Viral Diagnostics, Clinica, 2001

[35] Surviving Uncertainty: The Pan European Mediscience Review 2002, Deloitte & Touche 2002

**TABLE 14: ESTIMATES OF SALES OF *IN VITRO* DIAGNOSTICS BY TECHNOLOGY TYPE, 1999-2004[36]**

| TEST TECHNOLOGY/PURPOSE | SALES IN £ BILLION | |
|---|---|---|
| | 1998 | 2004 |
| Immunochemistry | 4 | 4.9 |
| Blood glucose detection | 1.5 | 2.2 |
| Microbiology & nucleic acid tests | 1 | 1.5 |
| Chemistry | 1.75 | 1.5 |
| Haematology & flow cytometry | 1.0 | 1.3 |
| Coagulopathies | 0.4 | 0.45 |
| Blood gases, electrolytes | 0.3 | 0.45 |
| Urinalyses | 0.3 | 0.4 |
| Others | 0.4 | 0.6 |
| **total** | 10.6 | 13.4 |

Recent industry estimates put the global market for diagnostic enzymes at £70 million. Marine-origin products already established in this sector include the fluorescent phycoerythrin from seaweeds and alkaline phosphatase from shrimp, both also used as laboratory research reagents. As more research reveals the ways in which specific marine-origin bioactives work, or materials interact with cells and surfaces, other potential uses in diagnostics may well emerge.

## 2.10 Research tools

Marine Organism Culture Collections can generate substantial income through fees and royalties from the supply of samples and subsequent development of bioactives or materials. The American Type Culture Collection raised over £8.1 million in fees in 2001[37]. CSIRO's Microalgae Research Centre (CMARC) in Australia has over 750 strains, mainly marine, which are supplied for research, teaching, commercial assessment and as aquaculture larval feeds, at approx. A$100 for 20ml[38]. The UK has 19 collections, several of which are relevant to marine biotechnology. Most are supported by the NERC (CCAP-Marine at SAMS, for example) and BBSRC (Newcastle's NICMB and the overall co-ordinating body the UKNCC, UK National Culture Collection) and charge a small amount for access (£25-30, occasionally £50) to other academic or commercial customers. If the promotion and marketing of the UK's marine collections were co-ordinated, additional income could be generated to maintain the collections and fund improved methods of curating, propagating and storing the accessions. CCAP and NCIMB have recently begun a collaboration to make better use of their resources.

---

36 D P Kelly in Medical Device Manufacturing and Technology, World Market Research Centre September 2000 p40

37 Marine Science Review, Report of Visit to Maryland & Virginia, New Park Management June 2001, chapter 4

38 contact microalgae@marine.csiro.au

Some marine sources for research reagents are well-known: the value of alkaline phosphatase isolated from frozen shrimp melt-water is approximately €110,000 for Novozymes, for example, and the catalogue price for 1000U is approx £50. Phycoerythrin, pre-conjugated with streptavidin, sells for approx. £110/100ml or £280/mg dry-form, and phycocyanin is also available. These seaweed-origin fluorophores are often used unconjugated as the fluorescent vital dye in cell sorting and are generally obtained outside the UK. There might be some potential for import substitution here.

The market for general-purpose biotechnology reagents has been estimated at over £0.7 billion by 2002[39], as shown below.

**TABLE 15: SALES ESTIMATES FOR BIOTECHNOLOGY REAGENTS[40]**

| SECTOR | SALES ESTIMATES £ MILLION | |
|---|---|---|
| | 2000 | 2002 |
| DNA sequencing reagents | 150 | 215 |
| General purpose biotechnology reagents & materials | 120 | 160 |
| Electrophoresis reagents | 100 | 150 |
| Tissue culture reagents & materials | 70 | 90 |
| Liquid chromatography reagents | 65 | 80 |

Extremophile and marine organisms have generated three of the most widely-known of modern bioreagents:

- Taq polymerase, a vital ingredient of the Polymerase Chain Reaction, from *Thermus aquaticus*, a hot-springs organism
- aequorin, the blue bioluminescent indicator of calcium flux, from the north-east Pacific coldwater jellyfish *Aequoria victoria*
- Green Fluorescent Protein, also from *Aequoria*, which converts aequorin to green light.

Following on the heels of Taq polymerase are Vent and Deep Vent polymerases, derived by New England Biolabs from the deep-sea hot vent relative, *Thermus thermophilus*. Laboratory reagent companies supply this in the UK at about £200 per 1000 units. Sales of PCR enzymes are estimated at up to £60 million annually world-wide, and the market for extremophilic enzymes is projected to grow 15-20% per year[41].

Other marine bioactives are in use as laboratory tools; manoalide and staurosporine from the US company AG Scientific Inc at £200 and £160 per mg for synthetic analogues, and natural bryostatin I from GPC Biotech Munich and LC

---

39 Theta Reports 767, *Biotech Research Reagents*, May 1998. Theta Publications Inc (part of PJB Publishing Ltd)

40 ibid.

41 quoted in The International Regime for Bioprospecting, Existing Policies and Emerging Issues for Antarctica UNU/IAS Report August 2003

Laboratories at £2,200 per mg[42] are examples. A recent discovery, too soon to have a price-tag, is that 6-bromoindirubin-3'-oxime, a constituent from Tyrian Purple, a dye found in a Mediterranean relative of the cone snail, inhibits glycogen synthase kinase-3 in vertebrate cells and stabilises and allows differentiation of human embryos and stem cells, thus simplifying their handling in the laboratory.

There are broader benefits from undertaking fundamental marine bio[techno]logical research, including an increased understanding of how cells interact and signal to each other in complex communities, how cells and biomaterials bind to inorganic surfaces, and how micro-organisms keep each other under control. The understanding of cell-to-cell signalling is one area in which there is considerable research strength in the UK.

## 2.11 Agriculture

Chitin and chitosans have been used widely in agriculture as soil conditioners, anti-fungal materials and components of seed coatings. Work at Washington State University is capitalising on the abundance of crab-shell chitin to produce fungicidal chitosan for control of potato blight, and lobster-shell waste has been put to practical use in production of organic potatoes on Prince Edward Island Canada for McCains Potatoes, after drying, grinding and extraction of astaxanthin[43].

More recently, marine biotechnology is yielding bioactives of interest. AIMS has isolated more than 30 potential herbicides since the late 1990s, in collaboration with the Nufarm company, and the AIMS spin-out ToxiTech has succeeded in growing one source, a marine fungus, on large-enough scale to yield enough material for initial trials. The US company AgriQuest is developing biopesticides from marine and other natural sources.

The global crop protection market consists of products applied to plants to kill or repel pests, including fungal diseases and insects, and to control weeds. In 2000, the world market was approx £17 billion, projected to rise to £23 billion by 2010[44].

---

42 Blaue Biotechnologie: Stand und Perspektiven der marinen Naturstoffe, Technologiestiftung Schleswig-Holstein, June 2003 pp 25-26

43 B Burles *pers. comm.* 2004

44 *The Global Crop Protection Industry in 2010*, Agrow Reports DS221, PJB Publications 2001

### TABLE 16: SALES OF CROP PROTECTION PRODUCTS WORLD-WIDE 2000[45]

| CROP-PROTECTION PRODUCT TYPE | EST. REGIONAL SALES 2000, £ BILLION | | |
|---|---|---|---|
| | EUROPE | USA | JAPAN |
| FUNGICIDE | 1.5 | 0.5 | 0.4 |
| POST-EMERGENCE HERBICIDES | 1.6 | 2.2 | 0.5 |
| PRE-EMERGENCE HERBICIDES | | 0.9 | |
| INSECTICIDES | 0.7 | 1.2 | 0.6 |
| COMBINED INSECTICIDE-FUNGICIDE | - | - | 0.2 |
| GROWTH REGULATORS, OTHERS | 0.2 | 0.2 | 0.25 |
| TOTAL | 4.4 | 5.0 | 1.9 |

Animal feeds, aquaculture feeds and pet food are three markets where marine-origin ingredients provide nutritional benefits and profitable markets. There is increasing pressure against the use of antibiotics and other pharmaceutical-type products in farm animals, so that such 'natural' extracts are attractive. A fermentation product from a terrestrial *Aspergillus oryzae* strain is used in animal feeds to produce stimulation of the animal's normal flora and fauna and increased performance and better feed use. β-glucans from yeasts are also reported to produce immunostimulant effects. This suggests the possibility that extracts of marine organisms might also have a positive impact.

The total sales of pet foods are astonishingly high, about £9.5 billion in the USA, £7.2 billion in the UK and £1.5 billion in France. Alginates and carrageenan are used as fillers and humectants. One avenue to explore is algal-based foods for pets, with high carotenoids, PUFAs and other components.

There is also a considerable market for microalgae as fresh food for organisms in aquaculture, including larval fish and crustacea, as well as filter-feeders such as clams, oysters and abalone, with at least 50 species or strains being in use or of potential value. The most important components of microalgae for nutrition are polyunsaturated fatty acids, sugars, vitamins, and sterols. There is also interest in chitin derivatives such as chitosans and glycosaminoglycans, which have health benefits for young fish and invertebrates, and some evidence that intact marine microbes are immunosupportive for salmon.

Given the current concerns about using fish in the feeds of farmed salmon and other species, as well as unfavourable comparisons between the texture of wild-caught and farmed fish, it would be worth investigating use of microalgal oils in fish diets.

Mixtures of marine and aquatic microbes are being widely used as probiotics, aids to healthy production in fish and shellfish farming and improvers of water quality in growing ponds. The probiotic effect is thought to be achieved by a combination of digestion of waste materials in the water (heterotrophic action), competitive exclusion of pathogens, production of enzymes that help fish and crustacean digestion, and release of nutrients from other aquatic organisms.

45 ibid.

The use of astaxanthin as an antioxidant in nutraceuticals has been mentioned; it is also an important additive for feeds for salmon and trout, crustacea and laying poultry, where a pink or orange coloration has an organoleptic benefit to the consumer.

## 2.12 Industrial uses and enzymes

There are existing processes using marine materials where use of enzymes of marine origin might be expected to improve economic efficiency; an example is the conversion of chitin into chitosan, which currently has an overall production efficiency of only 3%. There are also problems with management of wastes from fish processing and fish farming. Wastes are high in recoverable protein, collagens, oils, fatty acids, calcium and chitin but current processing systems add too much cost.

We believe there is potential in management of fish and shell-fish wastes for appropriate-scale biotechnology approaches that, without needing high-volume ultra-clean and consistent input, can still produce pure, high-quality, toxin-free outputs, ideally in separated streams. Mixed composting, adding wastes from other sources as balancers, could produce energy on-site as well as yielding a reusable residue, again in appropriate-scale and economically-effective systems. Intuitively, marine-origin enzymes should be better able to handle marine-origin wastes than enzymes from terrestrial sources.

Higher-technology development of marine microbes might be forthcoming as a result of a £20 million collaboration between Dow Corning and Genencor, aimed at understanding and using the physiology and biochemistry of marine plankton that utilise silicon. The companies hope to commercialise biologically-mediated silicone products for the life sciences, personal care, cleaning and fabric care markets, in the short-term, then move on to applications in diagnostics, biosensors, electronics and controlled delivery of active ingredients. The materials may also be used in developing new biochip-based devices with acute recognition and superior signal transduction capability. The ability of marine micro-organisms to build protein lattices for deposition of silica and other inorganic material in a nanostructured way holds out potential for bioproduction of silicon chips and other nano-structures.

In general terms, novel enzymes from marine sources may enter a market estimated at £2 billion; nevertheless, more than 90% of industrial enzymes are accounted for by fewer than 30 enzymes.[46] Specialised niche applications seem indicated, rather than a blockbuster enzyme.

## 2.13 Environmental management, remediation and energy

The global sensor technology market, both for environmental sensors and new forms of monitoring and exploration, is estimated at £2.8 billion per annum and is growing at 5 per cent per annum[47]. Marine organisms or molecules might find a place here, because of their reactivities. The UK company Remedios, a spin-out

[46] see http://www.diversa.com/markprod/mark/induappl.asp

[47] Marine Foresight Panel Ireland 2003

from the University of Aberdeen, has commercialised a novel eukaryotic biosensor based on a marine microbe, in which pollution concentrations can be measured by the degree of suppression of its bioluminescence. Remedios also uses other biosensor organisms that are representative of the bacterial strains found in the environment as well as those involved in bioremediation.

It is estimated that about 3.5 billion gallons (1.2 x $10^{10}$ litres) of oil are extracted at sea or are in transit across the oceans each day, and spillage is estimated at over 120 million gallons per year. Marine-origin biodegradable dispersants or *in situ* bioremediation by surface spray of oil-degrading microbes or enzymes would be welcome. Chitin is a chelator and powdered chitins have the ability to act as sequestrators of metal ions; dried microalgae such as *Chlorella* are powerful adsorbents of organic fluids. Other pollutants can be handled by marine micro-organisms: transferring mammalian or avian metallothionein genes to *Synechococcus* and *Chlamydomonas* produces genetically enhanced microalgae that are better at extracting and sequestering heavy metal pollutants from seawater. Research with a modified *Delinococcus radiodurans* has shown an ability to degrade organopollutants in radioactive surroundings.

There would be an exciting potential for genetically-enhancing marine organisms so that they are more capable of metabolising and detoxifying pollutants in sea water arising from human activities, particularly in concert with closed bioremediation bioreactors or process conduits.

A significant source of ecological pollution is ship ballast water. Problems caused by exotic organisms are well-known and there are, as yet, no really effective ways of dealing with this. Forcing ships to flush their ballast-holds while out in open water may help the final dock to avoid contamination, but the action simply shifts the load elsewhere rather than removing it altogether. It seems viable to explore whether a combination of 'probiotic' non-exotic organisms, marine viruses and suitable neutralisers might not eliminate stowaways in ship ballast water.

$CO_2$-neutral and renewable energy sources are of increasing importance due to climate change and the increasing global $CO_2$ concentrations in the atmosphere. One of these alternative energy sources is hydrogen, which can be used to generate electricity and heat in a fuel cell at a high efficiency. USA and Japan have invested in biological hydrogen production using photosynthetic bacteria and algae. The Dutch have established a significant national effort in this field, co-ordinated from the Food and Bioprocess Group in Wageningen University[48].

## 2.14 Bioengineering and new production techniques

Countries in the tropics and sub-tropics, such as Greece, Spain, Brazil, Australia or the American states of Florida and Hawai'i are able to use sunshine and exterior bioreactors for batch or continuous culture of microalgae in a way not yet possible in the UK. Here, effort can be directed into developing novel bioreactors for extremophilic microbes, creating optimised culture media and conditions of pressure, heat, cold, saltiness or electromagnetic radiation. Alternatively, and perhaps more cheaply, a focus on techniques for identifying genes of interest

[48] see http://www.biohydrogen.nl for information

without necessarily culturing or even identifying the producing organism, cloning and expressing reliably in reactor-adapted conventional organisms will be beneficial.

Similarly, due to the UK's cold and temperate waters, it is unlikely that we will emulate culturing of sponges for extraction of bioactives that is possible in Mediterranean and Adriatic waters; however, the University of Wageningen is culturing sponge primmorphs, clusters of cells that form small colonies, in closed reactors, which is a technology that can also be assessed in the UK.

# 3. MARINE BIOTECHNOLOGY IN THE UK

We identified a total of 21 companies involved in marine biotechnology or related fields and 49 Higher Education Institutions (HEIs) and other organisations, listed in **Tables 20-24** at the end of this Volume.

## 3.1 Companies

We have identified 21 companies that appear to have some connection with use or exploitation of marine resources. This is by no means a maximum, since there are undoubtedly more companies in the UK who use ingredients of marine origin as a basis for cosmetics, healthfoods, medical devices, foods and medicines.

Of the companies, 13 (over 60%) are Scottish, 7 are English and one (Carapacics) has its head office in Northern Ireland although it also has a site in Ayrshire – this has therefore been counted as a Northern Irish company. One service company (SEAS) based at SAMS (Scottish Association for Marine Science) has now merged with SAMS Research Services Limited, and one company is registered at Companies House but we have no other information about its activities. Two companies, Coastal & Marine Biotechnologies and Integrin also sell diagnostic and monitoring kits for environmental quality or toxins in shellfish, so are double counted in the table below.

**TABLE 17: TYPES OF COMMERCIAL ACTIVITY IN MARINE BIOTECHNOLOGY IN UK**

| COMMERCIAL AREA | NUMBER |
|---|---|
| Developing or producing **bioactives** | 9 |
| Service companies, consultancies | 4 |
| Producing **ingredients** eg agar, colloids for cosmetics, food, research use | 2 |
| Developing or producing **biomaterials** | 2 |
| **Environmental** applications | 5 |
| Unknown | 1 |

Most of the directly-involved businesses are based on culture collections, providing samples, extracts, bioactives, screening or storage services – only one of these (Aquapharm Bio-Discovery Ltd)) is also developing its own products; three are involved in monitoring of the environment or toxins in shellfish; one is developing medical materials from prawn wastes; another company is the commercial arm of a marine research laboratory but is also working on exploitation of raw materials from marine algae. Not all companies can be said to use primary marine biotechnology; some are using marine-origin microbes as an element of a wider collection for screening bioactives, others are using marine-origin molecules for diagnostic and monitoring purposes, or have service activities aimed at marine biotechnology. At least two have not so far started trading and one has been acquired by a US company since we began the work. Marine engineering companies are not included.

## 3.2 Academia and Research Institutions

Of the HEIs and organisations, 33 are in England, 10 are in Scotland, 4 are in Wales and 2 are in Northern Ireland (excluding the Centre for Innovation in Biotechnology, which is a joint-venture between the two Northern Ireland HEIs, and the Department of Agriculture and Rural Development for Northern Ireland, which is almost exclusively fisheries-oriented). Full lists are given in **Tables 21-24**.

**TABLE 18: UK'S STRENGTHS IN MARINE BIOTECHNOLOGY RESEARCH**

| ACTIVITY | UK BASE | COMMENTS |
|---|---|---|
| Marine viruses | Plymouth | novel enzymes and bioremediation |
| Actinomycetes | Newcastle | novel bioactives; some industrial collaboration |
| Oceanic marine science | Southampton | environmental management, deep extremophiles |
| Estuarine and coastal shelf marine sciences | Plymouth | new organisms, halophiles and others |
| Biofouling | St Andrews<br>Heriot-Watt<br>UG Millport | medical devices, marine engineering, boatbuilding, ballast-water management |
| Cell signalling | MBA Plymouth | human and animal disease processes and prevention |
| Cell cultures | SAMS, Newcastle | screening, new bioactives, biochemical models |
| Marine algae, plankton | Plymouth | environmental management, food safety |
| Bio-surfactants | SAMS | chemical and household industry |
| Bioreactors | Heriot-Watt | bioprocess for novel organisms |
| Bioactives | Aberdeen | screening for medical applications |
| Mariculture | Stirling | food, feed, research models, GM for |
| Chemistry | Plymouth | adaptation of biosynthesis to on-shore conditions |
| Genomics | St Andrews<br>Stirling<br>Plymouth<br>SFA | disease and breed improvement, environmental monitoring |

## 3.3 Current Initiatives in the UK

The most relevant sources for an examination of strategies for economic development are the studies examining the development of marine sciences in Scotland[49] and the potential for development of a science and technology cluster based on Plymouth[50]. In addition, NERC's M&FMB (Marine & Freshwater Microbial Biodiversity) programme provides a panorama of people and institutions

[49] *Marine Science in Scotland. A strategy for developing its potential* Draft Report February 2004, for Highlands & Islands Enterprise and Scottish Enterprise - unpublished

[50] Feasibility Study for the development of a marine science and technology (MST) cluster in Plymouth Final Report April 2003, GHK & BMT, for the City of Plymouth

currently working in areas of marine bioscience that might give rise to development activities.[51]

### *NERC's Marine & Freshwater Microbial Biodiversity (M&FMB) Programme*

We identified a very strong dynamism resulting from the early support of the UK's Biotechnology and Biological Science Research Council (BBSRC) of marine sciences, and the consistent support from the Natural Environment Research Council (NERC), for infrastructure such as research vessels, facilities and culture collection maintenance, but also for important integrative programmes including the Marine Biofouling and the more recent and ongoing Marine & Freshwater Microbial Biodiversity (M&FMB) programme, to which much reference is made in the text. The Technology Transfer activities of this programme are beginning to generate significant interest amongst the new companies seeking to commercialise marine-derived products and processes.

### *Marine Science in Scotland*

This study was carried out during late 2003 and early 2004 and aims to establish a strategy for developing and exploiting marine science in Scotland. Marine biotechnology is one of the topics addressed and it is seen as a "*seedbed for novel industrial developments*".[52] The study also includes a report addressing the possibility of creating an integrated marine science campus, to include research, applied sciences, commercial development and recreational aspects. The major proposal is to set up a Scottish Marine Science Alliance, representing academic, commercial and voluntary interests in the sector. The Alliance would therefore include members from SE (Scottish Enterprise), HIE (Highlands & Islands Enterprise), the Scottish Executive, SAMS, the RSE (Royal Society of Edinburgh), HEIs in Scotland, appropriate companies and a charity or NGO (Non-Governmental Organisation), to be funded by HIE and SE and staffed by a small secretariat. The role of the Alliance would be to establish the priorities for action within an overall strategy and delineate the implementation plan. Should this proposal be accepted, it would make sense for any initiative for marine biotechnology in the UK to take account of the Scottish Marine Science Alliance and ensure that appropriate integration takes place.

### *European Centre for Marine Biotechnology*

The European Centre for Marine Biotechnology (ECMB), sited at SAMS, Dunstaffnage, Oban, was conceived in 2000 and opened in 2004 as the first business incubator in the UK for marine start-ups. Its strategic function is to create a marine-oriented cluster of research, application and new business, with a stated aim of translating investigative and applied research ideas into products and processes for a variety of markets.

The national Culture Collection of Algae and Protozoa (CCAP) now occupies part of the new ECMB building, and the first new business occupant of the building will be Aquapharm Bio-Discovery Ltd. Occupants of the ECMB will have access to

[51] see http://www.nerc.ac.uk/funding/thematics/mfmb/

[52] Report by Professor I N McCave, incorporated into the report *Marine Science in Scotland*

SAMS's laboratory equipment, scientific expertise in marine organisms, biotechnology & molecular genetics, aquaria, algal culture systems and research vessels, as well as its human resources – over 100 marine-dedicated scientists and the NERC National Centre for Scientific Diving. They will also use shared facilities such as a library, conference suite and refreshment areas, with the aim of enhancing networking between business and research.

One of ECMB's goals is to become part of a network with similar activities across Europe and beyond; another is to establish trans-national development projects.

***Marine Science and Technology Cluster in Plymouth***

The City of Plymouth report confirms the strength of the region's education, training and academic research almost across the board of general marine-related areas of expertise.[53] Marine biotechnology itself is characterised as "*well-positioned, possibly requiring further development*" for biomolecular sciences, plankton science, marine chemistry and ecotoxicology, with the remaining 21 areas, including bioscience and physical science/engineering areas, characterised as "*less well positioned*".

The report identifies £20.9 million research revenues in Plymouth in 2002-2003, with £10.5 million (approx 50%) coming from the activities of **Plymouth Marine Laboratory** (PML) and the **Marine Biology Association** (MBA). Together with the Sir Alistair Hardy Foundation for Oceanographic Science, the University of Plymouth and the National Marine Aquarium, these have formed the Plymouth Marine Science Partnership (PMSP). However, set against the strengths in these institutions is "*a very weak exploitation record and an almost complete absence of local marine services*".[54]

Our view is that, in terms of fitting marine biotechnology activity into local marine businesses, development of new anti-fouling products, ballast-water clean-up and spin-offs of marine research in IT-linked sensing and navigation would be the most appropriate plan, since the most obvious local cluster is in boat design, boat-building, boat maintenance and marine electronics, mainly for pleasure craft (the latter a business of nearly £2.5 billion for the UK economy). The development of marine materials and molecules as aids in the oil and gas extraction and processing sectors would also be a realistic target, in view of the importance of these sectors globally.[55]

The outcome of this report is the strong recommendation that a Marine Science and Technology Park (MSTP) would answer most of the strategic goals for science and economic development and overcome many if not all of the challenges and barriers, although the report does not discuss whether the biological marine sciences and marine engineering and technology might have different needs and routes to fulfilment. The University of Southampton's focus on research and

---

[53] Feasibility Study for the development of a marine science and technology (MST) cluster in Plymouth Final Report April 2003, GHK & BMT, for the City of Plymouth page 23

[54] *Feasibility Study for the development of a marine science and technology (MST) cluster in Plymouth* Final Report April 2003, GHK & BMT, for the City of Plymouth page 40, and see Annex A for core competence mapping of PML and MBA

[55] see Table 3.4 of the *Feasibility Study*, page 26

applications in deep-sea marine engineering and technologies are complementary to Plymouth's shelf and coastal expertise and one attraction of the proposed Plymouth MSTP would be the potential for productive linkage with Southampton.

## 3.4 Location of activities in the UK/clusters

**TABLE 19: LOCATION OF RESEARCH AND COMMERCIAL ACTIVITIES**

| | ENGLAND | NORTHERN IRELAND | SCOTLAND | WALES |
|---|---|---|---|---|
| HEI, institute | 33 | 2 | 10 | 4 |
| Company | 7 | 1 | 13 | 0 |

Regionalism is very evident. Scotland leads in the establishment of companies based on marine bioscience or servicing this sector. There is some reason for this – 63% of the UK's seas are in Scotland's area (though not under its direct control) and seas-based economy has been important in Scotland, especially for the Highlands & Islands region. The Scottish economic development agencies - Scottish Enterprise and Highlands & Islands Enterprise and the associated Local Enterprise Companies - are sensitised to marine opportunities in a way that most of the rest of the UK is not. There is some evidence of support for development of marine sciences in the South West, building on the Plymouth Marine Sciences Partnership of Marine Biological Association Plymouth, Plymouth Marine Laboratory, the University of Plymouth and the Sir Alister Hardy Foundation for Ocean Science. Regionality is not seen as critical to the development of viable businesses based on marine biotechnology or its outputs, though it may be important for raw material extraction and marine engineering *per se.*

DTI's guide to cluster development[56] is useful in pointing to models for networked activity (Scottish Food and Drink, for example) and structural development (Enterprise Hubs) as well as providing insights into the necessary factors for successful community-building.[57] Support for clusters is mainly at regional and local level.

Clusters are a positive initiative and are of especial benefit to SMEs growing in a sector.[58] Through interactions with a cluster, HEIs get a clearer knowledge of what target industry sectors need, and companies can find research and applied technologies to address those needs.[59] This has implications for research-driven marine activities that have applications in more than one industrial sector.

In terms of 'clusters' of marine bioscience and biotechnology research activities, there are what can be described as developing clusters in Scotland (e.g.

---

[56] *A Practical Guide to Cluster Development: A Report to the Department of Trade and Industry and the English RDAs* December 2003 Ecotec Research & Consulting for DTI

[57] see Annex E of the Guide, which provides a 'quick reference guide' in table form

[58] Competitiveness: cluster-based policies 2002 The Cluster Competitiveness Group SA, Cerdanolya, Barcelona Spain

[59] Enhancing the Productivity of the British Economy: Cluster lessons and others September 2001 Paul Miller Trends Business Research

Aberdeen, Edinburgh, and at an early stage, Dunstaffnage[60]) and Plymouth[61] and Newcastle. Other centres of research activity include Glasgow, Essex and St Andrews. There is no formalised structure for networking and interaction between these and other sites with marine activity at institutional level; however, in Plymouth there is the Plymouth Marine Sciences Partnership, which forms a research and commercial support cluster, and across the UK there is collaboration between individual academics and departments in the NERC-funded M&FMB programme.

For marine biotechnology, important issues include how to make a marine biotechnology cluster work at national level and how to engage businesses who want to adopt best practice and learn more about new technology and science. A fairly comprehensive review of clusters in the UK could be useful in identifying regional end-user clusters that could be targets for marine biotechnology and its outputs, including regional strengths in biopharmaceuticals, chemicals, environmental industries, food, marine technology and classical pharmaceuticals.[62]

## 3.5 The context for Science and Innovation Strategies in the UK

### *Central Government*

The UK Government responded in late 2003 to the Trade and Industry Committee's report on UK Biotechnology[63] with commitments relevant to marine biotechnology. These include increases in the budgets of MRC (Medical Research Council) and BBSRC (Biotechnology and Biological Sciences Research Council) of 57% and 62% respectively for 2005-2006 compared with 2000-2001, with investment in cross-council research on stem cells and genomics, both areas to which marine biotechnology can contribute (cell-to-cell signalling and genome analysis techniques, as well as data on conserved genetic information). The Science **Spending Review** of March 2004 formally recognised the need to spend more on R&D.

The most detailed exposition of the UK Government's intentions with regard to the support of science, development and innovation is to be found in the **Science & Innovation Investment Framework** document issued in July 2004.[64] It codifies the Science Spending Review and begins with the bold but true statement that **"*Harnessing innovation in Britain is key to improving the country's future wealth creation prospects*"**. The main challenge for marine biotechnology is to work out how to take advantage of this explicit statement of policy and genuinely move forward, scientifically and in economic development terms.

---

60 *Assessment of Marine Science activities and Capability in Scotland (Abridged Version)* October 2001, Scientific Generics Ltd for Highlands & Islands Enterprise and Scottish Enterprise

61 Feasibility Study for the development of a marine science and technology (MST) cluster in Plymouth Final Report April 2003, GHK & BMT, for the City of Plymouth

62 Business Clusters in the UK – A First Assessment February 2001,Trends Business Research,

63 UK Biotechnology Industry. Government response to the House of Commons Trade and Industry Committee's twelfth report of the session 2002-03 Appendix to Sixth Special report of Session 2002-03, November 2003, The Stationery Office Limited, London

64 Science & innovation investment framework 2004-2014 July 2004 HM Treasury, DTI, DfES

The Government has established a number of targets, which are termed 'ambitions' in the document[65]. Ambitions relevant to marine biotechnology include ensuring the UK's competitive position in research excellence, growing the UK's share of internationally-mobile R&D investment and people, a stronger influence from end users of research on Research Council programmes and continued improvement of UK performance in knowledge transfer and commercialisation. It is widely accepted that the UK achieves a strong R&D showing internationally with lower average investment compared with other countries.

Other initiatives that are committed to by this document, and in which marine biotechnology could have a role, given greater or lesser degrees of ingenuity, include:

- responsibility of the Director General of RCUK for a strategic fund for emerging priorities and the health of disciplines (£70 million)
- far greater emphasis on multidisciplinary capabilities and actions in HEIs, driven by the Research Councils (therefore suggesting a greater cross-Council internal activity)
- establishment of a high-level horizon scanning centre of excellence within Government and RCUK, to be co-ordinated by the OST's (Office of Science and Technology's) Fore*sight* Directorate, complementary to the horizon scanning activities of individual departments
- the dedicated capital funding stream provided by SRIF (Science Research Infrastructure Fund) will be continued, with £500 million per year from 2005 onwards, and an additional £50 million will be provided for Research Council Institutes by 2007-2008.[66]

The investment framework document records the decision to continue with the building of a replacement for the research vessel *Charles Darwin*, scheduled for launch in 2007, and recognises the role of marine bioscience in completing the marine biodiversity inventory as a component of a Sustainable Earth systems multidisciplinary programme. These multidisciplinary programmes are seen to be of international importance and, implicitly, ones at which UK must excel. The examples given include:

- <u>Systems biology</u> - again something to which current marine bioscience, biology and biotechnology can contribute
- <u>Cognitive systems</u> - where the understanding of cell-to-cell signalling and consensus between cells of different types that has arisen from the study of biofilms and other mixed marine microbial communities may well give critical insights.

The RDAs (Regional Development Agencies) and Devolved Administrations (Scotland, Wales, Northern Ireland) are best placed to identify and support emerging companies with the potential for strong growth. That said, it is recognised that these might arise not in a cluster, but in a 'pocket of scientific brilliance'. DTI's Bioscience Unit has a role in promoting and facilitating collaboration between regions and devolved administrations in relation to

---

[65] *ibid.* page 6

[66] *ibid.* Chapter 2

bioscience. It will therefore be an important player in the development of a marine biotechnology networked community.

Industrial applications of biotechnology are the subject of the first report of the UK **Industrial Biotechnology Task Force** (IBTF) which was facilitated by DTI's Bioscience Unit.[67] The IBTF report highlights the potential that translation of biodiversity into new industrial products has. Because of their ability to cope with high and low temperatures, high pressure and salinity, enzymes and whole cells sourced from marine derived micro-organisms have numerous potential applications in industry. EU policy developers are increasingly recognising the significant potential for industrial applications of biotechnology, which should open up further opportunities for marine biotechnology. For example, the Environmental Technology Action Plan stresses the importance of industrial biotechnologies for the sustainable development of our society[68], the European Technology Platform on Sustainable Chemistry (launched July 2004) brings together leading chemical companies with the new, emerging biotechnology sector[69] and the European Plant Genomics and Biotechnology Platform[70]. Further developments could well include industrial biotechnology being featured in the next EU R&D Framework Programme (FP7).

***Regional aspects***

An effective strategy will need to take account of regionality and current approaches to support of economic performance in the regions. Scotland is better represented in academic excellence and business start-ups in marine biotechnology than other regions of the UK, a reflection of long-term commitment to marine economic enhancement. Nevertheless, Scotland ranks fourth for overall Gross Value Added (GVA, expressed as output *per capita per annum*), at £12,500. London dominates at £22,500, mainly contributed by service industries, followed by the South East at £16,000 and Eastern region at £14,000. Outside Scotland, marine biotechnology activity aimed at commercial exploitation is found mainly in the South-East, South-West and North-East, regions with GVA 10-25% lower than Scotland's. Generally speaking, higher-growth companies require better-trained people. Contribution to GVA mirrors the proportion of population and employees with higher education qualifications, which has considerable implications for the siting of new businesses and the potential impact of increased funding of science and engineering training for marine biotechnology in the regions. Investment is also required for development of commercial activities and, certainly in the private equity sector, investment per head of population is very much higher in London, the South East and East [71] compared with other regions.

Several programmes are now available to provide support for the relatively high-risk start-ups that will comprise marine biotechnology's exploitation efforts. In particular, the **Regional Venture Capital Funds** (RVCF) are intended to go some

---

67 Industrial Biotechnology: Delivering Sustainability & Competitiveness, IBTF. 2 December 2004 (see www.dti.gov.uk/biowise for further details).

68 For further information see http://europa.eu.int/comm/environment/etap/

69 For further details see Europabio's press release http://www.europabio.org/PRWB.htm

70 For further information see Europabio's press release http://www.europabio.org/PRGB.htm

71 Competing in the global economy: the innovation challenge December 2003 The UK DTI, Chapter 6

way towards addressing disparities and, with Regional Innovation Funds, University Innovation Centre funding and application of European Structural Funding, should be explored for support of regional activities in marine biotechnology. The **Research Council Follow-on Fund**, operated by NERC, BBSRC and EPSRC (Engineering and Physical Sciences Research Council), which supports proof of concept activities, closed its pilot scheme earlier in 2004 and has recently issued a new call.

The **Regional Science and Industry Councils** will be involved in steering R&D according to strategic goals and the needs of regional industrial sectors, and it is vital that marine biotechnology and its potential are brought fully before these.

Scotland has been a strong supporter of aquaculture, marine sciences and marine biotechnology and this will continue. Looking to the other Devolved Administrations, there are opportunities in Wales, where an £8.5 million Research Capacity Development Fund includes biosciences in its remit, and Northern Ireland, where there is considerable activity, including:

- a Research and Technological Development Fund
- a pilot Proof of Concept Fund of £3 million, established by Invest Northern Ireland and the Department of Enterprise, Trade and Investment
- the promise of £50 million in the Support Programme for University Research from 2004-2007
- £21 million from the UK-wide SRIF
- HEI-industry technology transfer support from the Higher Education Innovation Fund (HEIF), of £9 million from 2004-2007.[72]

[72] Science & innovation investment framework 2004-2014 July 2004 HM Treasury, DTI, DfES Chapter 9

# 4. MARINE BIOTECHNOLOGY IN AN INTERNATIONAL CONTEXT

There is a great deal of activity in marine biotechnology and associated marine technology world-wide. **Annex D** includes some details of funding and support for marine biotechnology in the UK and elsewhere.

## 4.1 International competition

From the competitive point of view, in the specific activity of building added-value businesses based on fisheries and aquaculture output, **Canada**, **Norway** and **France** are ahead of the UK, as far as we can tell.

In marine biotechnology itself, we see **USA** being definitely ahead of the UK. Germany and France are ahead in certain areas: **France** as a result of specific government support for networks such as GENOMER, programmes of commercialisation and individual research centres (Roscoff, Pleubian); **Germany**, as a result of a specific focus on commercial opportunities in the main marine research centres of GBF Braunschweig and the Institute for Marine Biotechnology Greifswald.

We do not consider **Japan** and **Australia** as immediate threats: Japan has invested heavily in marine biotechnology, with substantial cutting-edge work in deep-sea submersibles and high-pressure, high-temperature bioreactors over the past 20-25 years, but so far has not been very productive in biological applications of knowledge or international commercialisation. Australia, despite heavy investment and an impressive range of international collaborations, has only recently begun to be really active in licensing-out technologies and establishing start-ups from AIMS (Australian Institute of Marine Science), but the main impact is still local. The screening and pre-clinical arrangements of AIMS with the US National Cancer Institute may yet yield world-beating products but they are still far from commercialisation and, with the exception of some work on agricultural applications and sun-screen uses of marine bioactives, there is little other evidence of diversification.

Commercial challenges to the UK's existing efforts are in two main areas – <u>culture collections</u>, which have been well-commercialised from USA and Australia, and <u>prevalence of patents and prior art in pharmaceutical applications of bioactives</u>, certainly the case for USA. The UK can, however, be regarded as internationally prominent in marine actinomycetes, marine virus and biofilm research and it makes sense to capitalise on these strengths and move forward into a current window of opportunity.

It is more difficult to overcome the commanding position of the USA in marine biotechnology and marine-derived resources, because the USA started its support activities much earlier and it has put more money into it.

## 4.2 The European Union (EU)

UK initiatives need to be considered in an EU context. The Marine Board of the **European Science Foundation** (ESF) has published two Position Papers concerning marine biotechnology and marine science. The first of these, *Marine Biotechnology*[73], provides a foundation for relevant activities and initiatives at European and national level. The second[74] has a broader sweep and examines integration of marine science, including biotechnology, in Europe.

***Marine Biotechnology*** set out a vision of creating a 'concerted and focused initiative', extracting marine bioactives and using them in medicine, industrial processes and environmental monitoring. The key objectives[75] are of the nature that can be facilitated by strong, effective academic-industrial networks and cross-institution collaborative projects. The outputs of this report are more a list of desirable research and collaboration goals than a defined strategy, but these are set in a wealth of information showing that these goals are quite feasible. Elements of a strategy included in the paper are

- investment in enlarging the knowledge base on marine life
- funding focus on marine biology and biotechnological applications
- co-ordinated funding of interdisciplinary programmes
- focus on problem-driven research
- upgrading and efficient networking of European marine stations and centres
- developing systems for high-level specialist training
- effective encouragement of industrial involvement in the application of scientific research
- establishing new ways of obtaining technology transfer
- establishing a global network for dissemination of marine biotechnology discoveries to academic, industrial, business and public sectors
- promotion of public understanding of the use of marine organisms
- establish marine biotechnology firmly in EU Framework Programmes.

An important aspect of this is better use and deployment of infrastructure such as research vessels, remote undersea vehicles and other mechanisms for safely accessing and researching marine organisms.[76] A Marine Infrastructures Strategy Group is envisaged, which can contribute to the goals of creating an effective European Research Area (something that is of great importance in the context of the recent enlargement of the EU). Although the *Marine Research Infrastructures* report concerns the breadth of marine research, not just biosciences and biotechnology, it makes some points that are relevant, including the desirability of promoting regional centres of excellence and accessibility and co-ordination of infrastructure.

Active involvement of the UK in European Union projects, such as the **Network of Excellence in Marine Genomics**, has now increased. Investment in advanced

---

73 Marine Biotechnology, a European strategy for marine biotechnology ESF Marine Board Position Paper 4, December 2001

74 *Integrating Marine Science in Europe* ESF Marine Board Position Paper 5, November 2002

75 see page 3, Executive Summary of the ESF report *Marine Biotechnology*

76 *European Strategy on Marine Research Infrastructures* 2003, the Academy of Finland, for the European Strategy Forum on Research Infrastructure, Publications of the Academy of Finland 6/03

marine engineering for sampling, screening *in situ* and in Sea-Bed Observatories will help maintain the UK's position in Europe.

# 5. UK STRENGTHS, WEAKNESSES, OPPORTUNITIES AND THREATS (SWOT)

## 5.1 The SWOT Analysis

The UK marine biotechnology sector faces a number of challenges. One aim of this study was to establish a current view of the UK's strengths, weaknesses, opportunities and threats in the field of marine biotechnology. There have been a number of exercises at UK and European level, discussing and analysing the position with respect to development of marine biotechnology against what is perceived as its potential. The outcomes of some of these are presented and discussed in more detail elsewhere in this document. Our own work, based on a synthesis of existing information, a mid-project workshop and direct enquiry of interested parties, led us to the following analysis:

***UK Strengths***

- Excellent intra-national collaborations fostered by NERC (Natural and Environmental Research Council) and earlier BBSRC (Biotechnology and Biological Sciences Research Council) funded programmes.
- Good move to establish a M&FMB (Marine and Freshwater Microbial Biodiversity) Technology Translator.
- Individual centres of excellence exist (Southampton for deep-sea technologies, Plymouth for marine viruses, Newcastle for actinomycetes, Aberdeen for bioactives, Heriot-Watt for biofilm and applied marine biotechnology, SAMS for biocides and surfactants, for example).
- Overall:
  - Excellent activity in marine actinomycetes
  - Excellent activity in marine biofouling.
  - Excellent activity in marine viruses.
  - Potentially excellent culture collections.
  - Strengths in advanced engineering for ocean explorations.
  - Strengths in bioprocessing technology and some institutional desire to move ahead and fund this.
- Access to Faraday Partnerships for best practice and Knowledge Transfer Networks/Partnerships for enhancing science-base/industry collaboration.
- Ability to build on what natural resources activities we already have (mariculture, seaweed processing, aquaculture) and exploit added-value opportunities.

*Note: **Annex C** draws out the relevant conclusions of a report on the application of bioscience in the development of non-food crops, where there are some parallels which have helped inform our analysis.*

***UK Weaknesses***

- Lack of UK co-ordinated framework for marine biotechnology.

- Fragmented research community (in spite of NERC programme) with no planned cohesion, lacking clearly-visualised Centres of Excellence.
- Many research groups are small and lack critical mass compared with US (COMB or Scripps)
- Few large-scale or productive international collaborations.
- Still on the whole a mismatch between perceptions of value in the academic sector and in the commercial sectors.
- Not much follow-through from research findings to practical applications.
- Low investment base in business ideas arising from marine biotechnology or biosciences research.
- Few companies of any size and momentum to take new ideas forward.
- Reluctance of larger companies in pharmaceutical sector to take on marine bioactives.
- No inventory of resources.
- No integrated training programmes that start at base-line with marine biotechnology.

***Opportunities for the UK***

- Some viable business opportunities have already been identified that capitalise on the UK's science strengths in marine biotechnology; these include applications of biofilm knowledge in anti-fouling, use of marine viruses, development of new enzymes for biocatalysis, development of bioactives for infections (rather than cancers).
- The UK's work in marine bacteria and cell-to-cell signalling is highly relevant to R&D and commercial opportunities in other fields such as medicine and cancer prevention.
- Scientists working in marine biotechnology are aware that building a network will enhance interactions and improve opportunities for working with industry - the DTI's Knowledge Transfer Networks programme gives the opportunity to do this.
- There is an opportunity to use the SAMS experience of establishing the European Centre for Marine Biotechnology to explore the possibility of establishing other Centres of Excellence, either real or virtual, building on existing strengths.
- Funding programmes exist in Scotland (Proof of Concept projects, the Intermediary Technology Institutes, HIE provision of flexible funding) and the rest of the UK (Follow-on-Fund, Knowledge Transfer Partnerships, DTI Business Support Products) to move science-industry developments forward in application of the output of marine biotechnology
- The SBRI programme is a gateway for start-ups and SMEs to receive alerts on government procurement opportunities and to find out more about departmental and research council funding programmes[77].

[77] see www.sbri.org.uk

***Threats to the UK***

- France has significant strengths in deep-sea exploration and deep-sea bacteriology, which are somewhat in advance of ours.
- The French programme supporting exploitation of marine algae ('Valorisation des Algues') has also been important in legitimising commercial activity in this area.
- German investment in marine bioactives has been significantly greater and earlier than the UK's; Greifswald and other institutes are definitely focused on commercial opportunities; and MPI and GBF have strengths in genomics.
- If funding priorities are switched away from continuation of fundamental work to emphasise applied and exploitable aspects, there is a risk of falling away from the cutting-edge of science.
- The investment community currently fails to regard marine outputs with any seriousness; discussions are required.

## 5.2 Responses to the SWOT Exercise

To explore the relevance of these findings and to obtain feedback on the recommendations which those suggested, we sought responses from academic workers in the field and commercial or business support contacts. 66 questionnaires were sent out, 56 to academics and 10 to business and we received 10 detailed responses and 5 less-detailed responses, all of which provided insight into the goals and preferences. Of these, 11 were from the academic sector, 4 from the commercial or business support sectors. The main comments are summarised below:

- Respondents recognised the general panorama of strengths, weaknesses, opportunities, threats and recommendations as being comprehensive and were in general agreement with them.
- A priority of many respondents was identification of early- and mid-term opportunities for exploitation. Using Technology Translators was seen as a prime way forward. How to stimulate industry to invest in potential marine natural products was a prime challenge. A focus on microbial enzymes for biocatalysis might provide initial success and impetus.
- It was also seen as important to have a long-term commitment, to a 5-10 year programme, and one that allowed the advantages of devolved administrations to be deployed. Other preferred recommendations included investment seminars and partnering events, centralised support for fund-finding and applications, a Resources Review, using a network to raise awareness in the scientific community of the value of this type of activity to them as well as industry, and enhancing marine biotechnology training.

## 5.3 Initial Recommendations

Analysis of the SWOT findings resulted in recommendations in five activity areas:

- Maintaining and developing R&D base
- Sustaining networking
- Commercialisation and funding

- Scientific understanding of marine biotechnology and marketing
- Stimulate training and education

On further assessment, focus on funding was subsumed into the commercialisation element, leaving five major tasks to tackle (see **Chapter 6** for detailed discussion of recommendations, and **Volume 2** for background information, commentary, appendices and references).

# 6. STRATEGIC ANALYSIS AND RECOMMENDATIONS FOR ACTION

The following chapter focuses on the five key areas for action that were identified following the SWOT exercise (set out above). For each area, we have set out the suggestions that emerged during this study (see bulleted italicised list – in no particular order of importance), some further discussion, current activities and what we see as the key recommendations for action.

The remainder of this chapter then analyses the general approach to a strategy and reviews component parts, in the light of available programmes for support in the UK.

**Figure 1** and **Figure 2** at the end of this section illustrate the linkages between the areas for action and those who might be involved.

## 6.1 Maintaining and Developing the Science Base

Review resources within the marine sciences including biotechnology, and create accessibility:

- create an inventory of marine biotechnology resources: map the expertise, equipment and other useful facilities of each research and development group or centre that could serve as a community-wide resource – MBA and FMP could perhaps collaborate on this.
- examine the feasibility of setting up virtual or real cross-sector resources that call on the strengths of individual researchers and organisations, evaluating the potential of each HEI or institute to form part of such centres:
  - a Centre of Excellence for Marine Biotechnology Chemistry and Analytics, which isolates, characterises, establishes synthetic methods and develops appropriate analytical tools for novel bioactives and biomaterials from marine sources.
  - a Bioprocessing and Scale-Up Centre, which finds the best ways to mass-culture source organisms, whether open cultivation, closed bioreactor or by use of genetic engineering, and builds and validates the industrial-scale systems required, as well as putting in place the relevant knowledge from chemistry and analytics.
  - a Centralised Marine and Industrial Culture Collection facility, with suitable depository, viable storage and validation facilities, running at commercial rates.
  - a Centre for Marine Biotechnology Pharmaceutics & Formulation, which establishes the commercially-viable forms for marine bioactive-based or biomaterials-based products, in collaboration with industry.

### *Discussion*

The proposed approach is a way of drawing together the diversity of expertise and overcoming the geographic separations within the marine biotechnology community, also of recruiting assistance cross-discipline and of making strategic links with pre-existing activities in other sectors, such as the ITI (Intermediary Technology Institute) Life Sciences, the UK Centre for Tissue Engineering or the Advanced Bioprocessing Centre, Brunel University.

HIE/SE's Marine Science Strategy for Scotland recommends that major participants in marine biotechnology should hold periodic brainstorms to maximise enthusiasm and opportunities for synergy; this can easily be adopted on a nation-wide basis.

***Key recommendation for action:***

The FMP-Marine Biotechnology Group will consider further, in collaboration with a network of researchers and companies already established in the sector, the strengthening of one or more centres of excellence in discussion with appropriate bodies (e.g. RCUK - Research Councils UK, DTI and regional development and enterprise agencies).

## 6.2 Sustaining Networking

Create a community for scientists working in marine biotechnology:

- establish a new web-site or build on an existing one
- provide:
    - scientific content.
    - market information relevant to development and commercialisation of the outputs of marine biotechnology.
    - a discussion forum for scientists and industrialists.
    - virtual conferencing.
    - resource matching between science and industry.
- since Knowledge Transfer Network funding might be appropriate for this, make a case to DTI for support of this for marine biotechnology.

***Discussion***

Two aspects emphasised by respondents during this project were that, though there is a great deal of research going on, and the NERC has played an important catalytic role, there is no other effective platform for networking within the science community, especially to bring in people from disciplines other than marine biotechnology and biodiversity studies. There are also no platforms, networks or fora in which the science community and the industrial end-user communities can come together, which is possibly the main barrier to speedy uptake of new ideas by industry - a reason why a Knowledge Transfer Network approach may be particularly productive for this sector.

Effective networking can be encouraged by organised workshops, seminars and partnering events that deal with marine biotechnology in general, and presentations by marine biotechnologists at fora where end-users are in attendance, as well as the development of a dedicated web-site that serves the interests of the entire community.

***Current activities:***

Networking is in train through the M&FMB programme, as it brings diverse researchers together. NERC is also funding a Knowledge Transfer Network on microbial biodiversity and marine biotechnology and this can be built on to extend beyond microbial biodiversity to biotechnology, given suitable resources.

***Key recommendation for action:***

By building on existing funded networking activities by the research councils, such as the NERC M&FMB (Marine & Freshwater Microbial Diversity) programme, and new initiatives such as the Knowledge Transfer Network funded by the DTI (Department of Trade and Industry), a pan-UK approach to marine biotechnology will be developed.

## 6.3 Commercialisation and Funding

Identify viable business opportunities that the market wants, benchmark these and assess their feasibility:

- realistic candidates for the above process seem to us to be:
  - applications for marine biofilm knowledge in medical and other industrial anti-fouling.
  - marine viruses for environmental and industrial use.
  - microbial enzymes for biocatalysis, including those from marine viruses.
  - bioactives for infections (rather than cancers).
  - added-value materials from raw material processing.
- make full use of the Technology Translator concept.
- develop a technology transfer methodology that can be applied to future outputs.
- explore, at an early stage, the potential for transfer to other sectors of the UK's knowledge in marine bacteria and cell-to-cell signalling.
- identify technology gaps where marine biotechnology could meet areas of need for industry (including non-biomedical).
- make use of Scottish Proof of Concept projects and Intermediary Technology Institutes, using Scotland's marine scientists as the entrée.
- make use of HIE flexible approach to funding research and development.
- make use of UK Follow-on-Fund, Knowledge Transfer Projects and SBRI (Small Business Research Initiative) service for directed development of the research outputs of marine biotechnology.
- provide some centralised planning and assistance for marine biotechnology researchers and SMEs via information, web-site links and, if appropriate, a hands-on service.
- the investment community continues to be interested in innovative approaches to manufacture, healthcare and high-tech, and there should be no barrier to marine biotechnology feeding into this, provided that the targets are clear and the business strategies for reaching them are well-argued; this requires the marine biotechnology community as a whole to promote what is on offer to the investment community, using well-thought out seminars, conferences and partnering activities.

### *Discussion*

With regard to delivering the needs of industry, a UK-based respondent has pointed out that:

> *"there's a kind of institutional or cultural void between the people with relevant academic competencies and the ultimate end users (oil companies, pharmaceuticals, etc). Other sectors have a fertile middle ground of "appliers" – IT, for instance. Academics who are good at being academics are not always the risk-coping entrepreneurs that these high-investment high-tech outputs demand, and experience seems to suggest that the market for one brilliant idea is more finite than university researchers expect."*

This is consistently a difficulty faced by an academic community seeking to exploit its discoveries. The most effective ways of overcoming the perceived and actual gaps are:

- industry-led contract-based work that springboards off the academic discovery.
- R&D centres funded by industry consortia that focus on industry problems.
- creation of networks, fora or platforms that bring academic researchers and industry together.

The latter has the capacity to pinpoint industrial problems, challenges, gaps and needs on a broader scale, review research innovations from diverse sources that could answer these, and develop collaborative projects to do this. We tend to favour this route as a better way forward; if nothing else, it also allows each community to make internal links (ie academic-academic or industry-industry) that otherwise might not happen.

Funding of basic knowledge in marine biodiversity and biotechnology is an issue. By 1995, the USA realised how far behind Japan it was falling. Only £22million in 1992 of Federal biotechnology research funding was going into the marine sector compared with £290 million in Japan, and this included infrastructure. The application of funds for research alone in marine biosciences and biotechnology in USA is now significant - The Sea Grants programme, the Microbial Observatories (see **Annex D**) and even the Californian BioStar/University of California Discovery Grants total almost £56 million. But these programmes are dwarfed by the Census on Marine Life programme, a >45-country collaboration, with core funding from the Alfred P Sloan Foundation and total funds of £600 million over 10 years.

The UK can take part in activities such as these but the research and applications communities cannot hope to receive funding at such a scale, even comparatively-speaking. The UK Research Councils have supported different aspects of marine science and biotechnology; currently, the most important activities in biosciences lie within the Marine & Freshwater Microbial Biodiversity programme, supported by the NERC with funding of approx. £7 million. Commercialisable results are arising from this programme. One target might be to persuade other research councils and government funding sources to include support for applied marine biotechnology in their budgets and policy thinking.

This needs to be addressed as a matter of urgency, and it may require some degree of flexibility on the part of government to respond; a way forward would be for the scientific and applications communities themselves to come up with proposals for support that stimulate the interests of more than one funding source in such a way that they feel able, perhaps obliged, to work together.

In order to accelerate development in this sector, creating projects in the new Knowledge Transfer Networks (KTNs) and Knowledge Transfer Partnerships (KTPs) programmes is one opportunity. Making use of existing integrative mechanisms such as transfer of best practice from Faraday Partnerships is another.

The investment community in UK is, on the whole, conservative. Biotechnology-based human health companies have produced some success stories but have also produced high-profile failures. Investing in this area is generally the province of a few high-profile specialists such as Prelude, Advent, Apax Partners in the UK, Soros Perseus in US, or technology consultancy-associated funds such as TTP Ventures in UK. There is no real precedent in the UK for involvement of such companies in marine biotechnology exploitation.

***Current activities:***

Some **commercialisation** is already underway, either as activities by individual scientists or organisations, or through the medium of technology translators devoted to one particular programme, as is the case for the NERC's M&FMB programme. Outcomes can be enhanced by appropriate support in a networked environment, such as provided by an interest grouping or partnering activity. There is no current specific focus on **funding** for exploitation of outputs of marine biotechnology. It is necessary for entrepreneurial researchers and start-ups to search for funding from a variety of sources, including existing public programmes and investor organisations. The establishment of regional venture capital funds and maintenance of the Enterprise Investment Scheme may assist SMEs, provided they have a good story to tell about why marine biotechnology offers good prospects to investors.

***Key recommendation for action:***

The FMP-Marine Biotechnology Group will develop a register of interested venture capitalists, and garner support from biotechnology trade associations (e.g. the BIA), to develop a portfolio of funding opportunities, with the assistance of the DTI.

## 6.4 Scientific Understanding of Marine Biotechnology and Marketing

Address concerns about the marketing and image of the sector:

- organise science missions, GlobalWatch missions, involve more scientists in trade missions.
- encourage and support the presence of UK marine biotechnology scientists at conferences and workshops that relate to end-users.
- prepare publicity using case studies of successful development and application of marine biotechnology, targeted at four sectors – academic, industrial, public and intermediaries (including government and funders).
- use whatever additional Government sponsorship is possible for disseminating information on biotechnology and innovation.

- enhance opportunities for the UK to reach level pegging and aim to overtake France and Germany using appropriate, strategic collaborations, funded by EC programmes or other instruments depending on scale and scope.
- use sensitive and consistent lobbying to ensure a realistic balance in support between fundamental marine bioscience, including biotechnology, and development and commercialisation of the sector.

***Discussion***

In order to establish the gravitas of the UK's research activity in the minds of stakeholders and demonstrate the contributions it can make to scientific excellence, competitiveness and economic progress, promotion activities are essential. Success breeds success. There are success stories in marine biotechnology, even if they do not always come from the UK (eg pseudopterosin). The UK has scientific excellence in several areas that are intrinsically fascinating (oceanic engineering, marine viruses, extremophiles from coastal areas, for example) and others that hold out great promise for environmental and health benefits, topics of current public and policy interest (eg biofouling, cell-to-cell signalling, actinomycetes and other microbes).

Though individual efforts should not be prevented, to make the most of the opportunities and the UK's strengths in an efficient way argues for a co-ordinated approach with a focal point for information on the science and benefits of UK marine biotechnology. Conferences, workshops and partnering events with the specific theme of products from marine science will also add to the impact of activities in this area, adding value to research funding and assisting commercial prospects.

***Current activities:***

Support of marine biotechnology GlobalWatch, Trade and other special missions are helpful.

***Key recommendation for action***

New initiatives in public understanding of science will be harnessed to develop readily accessible information that fulfils a promotion, PR and marketing objectives.

## 6.5 Stimulate Training and Education

Create a co-ordinated cross-disciplinary training effort

- build on existing excellent marine science and biology courses and the two marine biotechnology courses that are available.
- benchmark, review and if appropriate transfer best practice from within the Faraday Partnerships in establishing modular cross-institution courses.

***Discussion***

Training is a common theme in high-technology bioscience sectors. We believe that here, too, a collaborative approach is best, in order to make use of scarce resources. This is why we suggest reviewing existing marine bioscience and marine biotechnology courses and, by taking best practice from cross-institutional and/or modular higher education in other areas (eg from UHI Millennium Institute, Faraday Partnerships, inter-institutional centres of excellence or Open University), assess the feasibility of establishing similar training courses, which can be more effectively funded for this role than trying to establish a number of fully-formed but essentially competitive courses at several HEIs. Individuals in the marine biotechnology community may also benefit from training in the communication of science to other scientists, lay public and groups such as investors and policy-makers.

***Current activities:***

The Government has recognised the importance of training across the sciences and there is considerably more funding available for training programmes, including basic skills, scientific skills and business knowledge. Contact with RDAs and local Skills and Training Councils will enhance the possibility of obtaining financial support for training programmes geared to the special needs of marine biotechnology and companies based on this.

***Key recommendation for action:***

Working with the Funding Councils and Research Councils, the FMP-Marine Biotechnology Group will seek to identify opportunities for modular cross-institution courses in marine biotechnology, including specialist technical skills training.

# 7. DEVELOPING A STRATEGY FOR SUCCESSFUL SCIENTIFIC AND ECONOMIC DEVELOPMENT OF MARINE BIOTECHNOLOGY IN THE UK

## 7.1 Analysis

Any strategy for development of a technology-based sector needs to recognise both scientific and commercial aspects:

- Recognition that the field in question has made genuine scientific achievements.
- Showing that research in the field can contribute to economic advancement.
- Identifying the players and contributors necessary for a successful strategy.
- Capacity-building for promotion and marketing.
- Developing programmes of scientific support for innovation creation.
- Using programmes for economic development to transfer knowledge and technology and build marketable products and services.
- Harnessing willingness-to-fund.
- Establishing the best facilitation mechanisms.

## 7.2 Possible mechanisms

The DTI Innovation Report *Competing in the global economy: the innovation challenge* views innovation as the source of better products and services, cleaner and more efficient production processes and improved business models, with positive impacts on consumers, businesses and the economy alike.[78] A strong message in this report is the Government's commitment to realising the UK's potential through creating a more demand-led, responsive and flexible training system. It recognises that cross-departmental action on fostering innovation is still required, building on DTI and OST activities.

The report promises direct measures in seven key areas:

- generating new knowledge that is transferable.
- enabling companies to better transfer and embed that knowledge.
- filling gaps in access to funding.
- stimulating competition and entrepreneurialism.
- encouraging suppliers to Government and other public sector procurement agencies to become more creative.
- promoting appropriateness of regulation.
- enhancing networks and collaboration.

More recently, the Science and innovation investment framework document points the way to actions for 2004-2014. These initiatives are there to be taken

[78] Innovation Report: Competing in the Global Economy the UK DTI September 2003

advantage of by players in the marine biotechnology sector in moving towards an overall goal of enhancing UK's productivity and competitiveness.

In broad terms, scientific development includes actions such as support for integrated or directed programmes, cross-institute and trans-national projects in identified subject areas, increased focus on training and on knowledge transfer by placements and collaborations, science-oriented networks and scientific PR (public relations and communications). In the UK, these commonly fall within the remit of the research councils making up RCUK, private research funding organisations (Wellcome, for example), trans-national funding bodies such as the European Union (EU), and the HEIs (Higher Education Institutions) and PSREs (Public Sector Research Establishments) themselves.

Economic development includes actions such as support for technology transfer, prototyping and capacity-building for SMEs (small and medium-sized enterprises), academic-industry networks or platforms, investment funds targeted at a specific sector, export promotion and trade missions, cluster-building and infrastructure support, including training. Conventionally, DTI, Regional Development Agencies (RDAs) and Skills and Learning Councils are the supporting and organising bodies for such activity. A more recent actor on the scene is NESTA, the National Endowment for Science, Technology and the Arts.

The UK Government's approach to funding of technology innovation and economic development has been overhauled and there are considerable opportunities for marine biotechnology in this[79] (**Annex D** expands on possible sources of funding and support).

## 7.3 Targets

The targets are to:

- identify the elements and mechanisms for successful scientific and economic development of marine biotechnology in the UK
- scope the scale of requirements
- identify players and contributors to investment/funding packages
- define feasible investment/funding strategies
- make recommendations for achieving all this.

## 7.4 Possible next steps

A sequence of events in encouraging the development of marine biotechnology in the UK could therefore include the following:

- defining the sector, creating its message and engaging enthusiasm
- supporting a network as a facilitating mechanism
- instituting a directed or thematic programme of research that validates the commercial potential of scientific innovations, for example into identifying

79 see Competing in the global economy: the innovation challenge December 2003 The UK DTI and Science & Innovation investment framework 2004-2014 July 2004 HM Treasury, DTI and DfES

and validating marine outputs for the chemical, pharmaceutical and biotechnological sectors

- supporting relevant centres of excellence
- supporting research-industry-investor knowledge and technology transfer as appropriate
- general support of communications, public relations, image-building, credentials of the sector.

## 7.5 Participants

The aim of facilitation mechanisms is primarily to encourage industry and research to work together, to enhance the credentials of research in terms of ability to fill technology gaps or answer some of industry's strategic needs, and to legitimise industry's needs in the eyes of researchers. Facilitation should also strengthen the partnership between academic and industry sectors in the areas of education and training and enhance the willingness-to-fund of investors. Mechanisms may be passive, in the sense that programmes are provided by government or locally and people may take advantage of them, or active, in the sense that there are protagonists driving activities forward. Establishment of a small, active team representing the interests of a particular academic-industry grouping is always more effective in focusing strengths and leveraging energy than moving immediately into a broad, dispersed kind of network. If Government identifies a particular area for action and undertakes to support such a group by targeted funding, this can be genuinely synergistic.

There is a complex connectivity between players and contributors in the marine biotechnology sector. If a centrally-active facilitation organisation is seen as key to establishing a successful strategy, it might work as shown in **Figure 2**.

IACMST, the Inter-Agency Committee on Marine Science and Technology, may have a role, in that it is possible to work with a member department such as DTI to encourage an Open Forum on the development and exploitation of marine biotechnology, or work with IACMST's marketing liaison function to set up an industry-research conference.

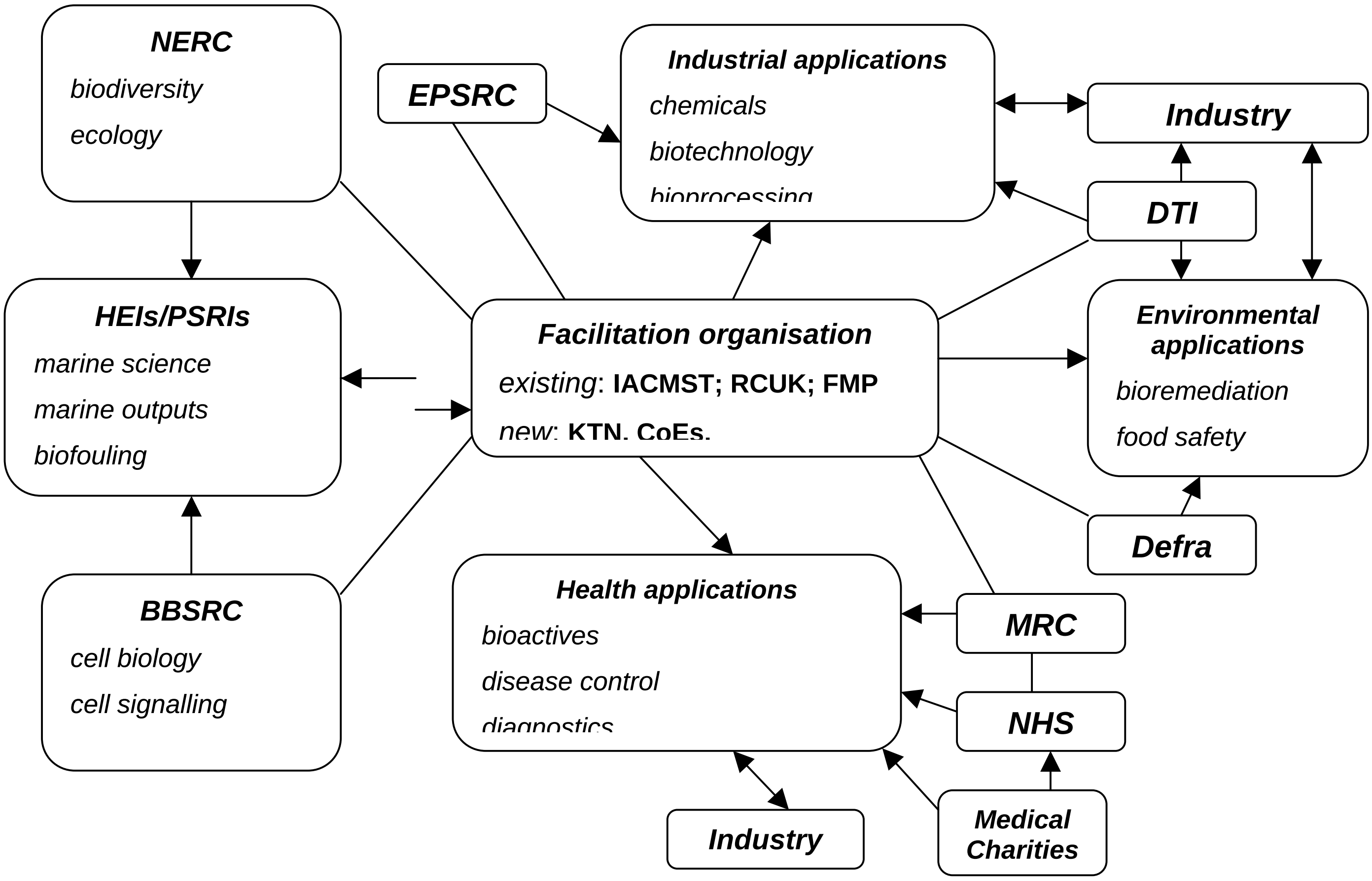
## 7.6 Costs

A cost estimate for a strategy support programme can be constructed from knowledge of the costs of reasonably comparable programmes and projects, including some marine science ones (see **Table 25** in **Annex D**). Following a decision on what strategy to follow, deeper analysis will allow the development of more accurate and coherent costings and a plan that identifies realistic sources of funding, nationally and internationally, public and private. **Annex D** also summarises potential sources of funding and support.

## FIGURE 1: RECOMMENDATIONS AND POSSIBLE ACTIONS IN A MARINE BIOTECHNOLOGY STRATEGY

| | | |
|---|---|---|
| **Maintaining and Developing R & D Base**: Review resources, create accessibility to scientific and industrial communities | Create an inventory of marine biotechnology resources, map expertise, equipment<br>Examine the feasibility of setting up virtual or real cross-sector Centres of Excellence | Explore and use all available Government Initiatives<br>Identify initiatives in other sectors – chemistry and analytics, bioprocessing, pharmaceutics and formulation; Scottish ITI, UK equivalents<br>Consider ways of improving Culture Collection economics |
| **Networking**: Create a community for scientists, influencers and end-users working in marine biotechnology | Test models for networks very actively<br>Establish a web-site<br>Create workshops, seminars and fora<br>Bring together scientists and industry, plus funders, government, charities, patient groups, end-user groups<br>Engage in brokerage and partnering events<br>Build knowledge base of relevant science and business | Approach DTI about Knowledge Transfer Networks<br>Read, understand and use all initiatives included in Government's Innovation strategies<br>Consider Centres of Excellence – will they contribute? |
| **Commercialisation and Funding**: Identify viable business opportunities, benchmark, assess feasibility; identify and obtain funding | Applications for marine biofilm knowledge in medical sector<br>Anti-fouling paints<br>Marine viruses for environmental and industrial use<br>Microbial enzymes for biocatalysis<br>Bioactives for infections, inflammations, cancers<br>Added-value materials from raw material processing<br>Transfer UK knowledge in marine bacteria, cell-to-cell signalling<br>Create a service providing centralised information on public and private funding and assistance with applications<br>Increase interactions between researchers and investment community<br>Improve the visualisation and communication of business concepts | Technology Translators<br>User-friendly tech transfer methodology<br>Identify technology gaps by dialogue with industry<br>Focus on Markets<br>Scope the opportunity<br>Build a Network?<br>Use web-site as open door<br>Understand and use available Government initiatives<br>Plan workshops, seminars and partnering events<br>Training in communication skills for business |
| **Scientific PR and marketing** | Develop a coherent profile of UK marine biotechnology and a clear message that marine biotechnology can contribute to a better future and to the economy; get over the message to the people and organisations that count | Draft an agreed briefing paper<br>Make use of Government initiatives in science communication and public understanding of science<br>Co-ordinate UK Marine Biotechnology presence at overseas events |
| **Training:** undergraduate, graduate and post-graduate levels for marine biotechnology; business skills | Create a co-ordinated cross-disciplinary training effort | Build on existing marine bioscience and biotechnology courses<br>If appropriate, transfer best practice from modular cross-institution courses eg FPs, OU<br>Make use of Government initiatives in training |

## FIGURE 2: CONNECTIVITY BETWEEN RESEARCH AND SUPPORT IN SCIENTIFIC DEVELOPMENT AND COMMERCIALISATION




*Notes:*

*In Figure 2, double-headed arrows refer to collaborative development; single headed to funding support, in the case of RCUK, NHS (National Health Service) and Government, or flow-through of knowledge/technology, in the case of applications. The linkages of RCs and DTI to a possible integrating body might be via funding, policy discussions, directed programming, eliciting of further Foresight activities or other scientific and economic development instruments.*

*The above does not take into account interactions with RDAs, Devolved Administration support bodies, Local Authorities or Government departments such as DfES.*

# ANNEX A: COMPANIES

## TABLE 20: COMPANIES ACTIVE IN ASPECTS OF MARINE BIOTECHNOLOGY IN THE UK

| COMPANY | CONTACT | SECTOR |
|---|---|---|
| **Actinomed Ltd**<br>Newcastle | Alan Blakey; Prof Mike Goodfellow, Dr Alan Ward | A very new start-up looking at bioactives from novel marine actinomycetes; targeting antibiotic-resistant bacterial pathogens |
| **Aquapharm Bio-Discovery Ltd**<br>European Centre for Marine Biotechnology, Dunstaffnage Marine Laboratory, Dunbeg, Oban, Argyll, PA37 1QA | Dr Andrew Mearns Spragg CEO<br>T: 01631 559390<br>andrew@aquapharm.co.uk | Founded by Heriot-Watt University post-doc; has >1000 microbes in library and three candidates – AQP001, new source of astaxanthin for aquaculture feeds, APQ002, process for anti-oxidant flavonoids and APQ001, new antibiotic; gained a Smart:Scotland award in 2001 for the astaxanthin |
| **BioDiversity Ltd**<br>Business Innovation Centre, Rm 23/24, Innova Park, Mollison Avenue, Enfield EN3 7XU | T: 020 8350 1278<br>F: 020 8350 1255<br>info@bdlabs.com | BioDiversity supplies microbial samples, fermentation biomass extracts and metabolites and has a focus on fungi, which may be relevant to marine bioactives |
| **Biolitec Pharma Ltd**<br>Breasclete, Isle of Lewis, HS2 9ED Western Isles<br>(HQ Heriot-Watt Research Park, Edinburgh) | T: 01851 707500<br>F: 01851 621368 | Originally Scotia Pharmaceutical's photodynamic anti-cancer therapy division, sold to Singapore Technologies when Scotia folded and then bought in 2002 by BioLitec AG of Germany; down-sized in 2003-2004; was researching bioactives from seaweed |
| **Carapacics Ltd**<br>c/o QUBIS Ltd<br>Lanyon North, The Queen's University of Belfast, University Road, Belfast BT7 1NN, Northern Ireland | Ian Scade, MD<br>c/o T: 028 9068 2321<br>F: 028 9066 3015 | Founded in 1999 in Northern Ireland as a spin-out from Queen's University Belfast, Carapacics has developed technologies for producing added-value chitin, chitosans, collagen and biocomposites from prawn wastes. The company began a joint venture in 2000 with a US company Ovogen to carry out similar development and commercialisation work with egg shell membrane. Carapacics has a Scottish site in Ayrshire. |
| **Coastal & Marine Biotechnologies Ltd**<br>Tamar Science Park, 1 Davy Road, Derriford Plymouth PL6 8BX | Ian McFadzen, Director<br>John Wedderburn, Director<br>T: 01752 764430<br>F: 01752 772227<br>cmb@cmbiotech.co.uk | A spin-out from the Plymouth Marine Laboratory & NERC, founded in December 2001; has developed water quality assays using shellfish embryos and itself spun-out **BioVault Ltd**, a human cell and tissue cryopreservation company, on the back of its proprietary freeze-drying technology; expanding to include 'UK's and EU's first bio-repository facility' |

**TABLE 20: CONT**

| COMPANY | CONTACT | SECTOR |
|---|---|---|
| **Commercial Microbiology Ltd**<br>Kettock Lodge, Campus 2, Aberdeen Science Park, Bridge of Don, Aberdeen AB22 8GU Scotland | Stephen Maxwell, Managing Director; Alison Gardner General Manager<br>T: 01224 706062<br>F: 01224 706012<br>info@commercialmicrobiology.com | Bioremediation: Development of biological products for odour control, oil spill clean-up, drill cutting remediation, effluent treatment |
| **Croda International Plc**<br>Cowick Hall, Snaith, Goole, East Yorkshire DN14 9AA | T: 01405 860551<br>F: 01405 861767 | Colloids company, originally animal-origin, now widely-sourced including marine; cosmetics formulations sold via subsidiary Sederma |
| **Destiny Pharma Ltd**<br>Sussex Innovation Centre, Science Park Square, Falmer, Brighton, BN1 9SB | Dr Bill Love, CEO<br>T: 01273 704 440<br>F: 01273 704 499<br>wl@destiny-pharma.demon.co.uk | Working with Prof Peter Revell (University College London-Royal Free Hospital) and Prof Andrew Lloyd (Brighton) on alginates and chitosans for tissue engineering scaffolds |
| **Drug Discovery Ltd**<br>Royal College Building, 204 George Street, Glasgow G1 1XW | Dr Alan Harvey<br>T: 0141 548 4534<br>info@drugdiscovery.co.uk | Strathclyde Institute for Drug Research's commercial arm – bioactives from marine sources, as well as other microbes and plants, specifically targeting asthma, arthritis, cancer and rejection of transplantation. |
| **Hebridean Biotech Ltd** | | A new company, set up to commercialise essential fatty acids produced in marine algae; awaiting results of an application for SMART funding, currently dormant |
| **Integrin Advanced Biosystems**<br>Marine Resource Centre, Barcaldine, Oban, Argyll PA37 1SE Scotland | Dr. Charles Bavington charlie@integrin.co.uk, Claire Moss claire@integrin.co.uk<br>T: 01631 720 765 | Marine Natural Products: international libraries of marine extracts, screening for interesting biological activity, bioactive characterisation, delivery into pharmaceutical drug development pipelines; tests for shellfish toxins; development of new culture methods for marine invertebrate cells and for bacterial symbionts to accelerate development of bioactives |
| **ISP Alginates (UK) Ltd**<br>Ladyburn Works, Dipple, Girvan, KA26 9JN Strathclyde | T: 01655 333000<br>F: 01655 333100 | Major producer of alginates and other marine hydrocolloids, using mainly imported raw materials. Contributes approx. £30m turnover to Scotland's marine economy. |
| **Laxdale Ltd**<br>Kings Park House, Laurelhill Business Park, Stirling, UK FK7 9JQ. | T: 01786 476000<br>F: 01786 473137 | Developing treatments for central nervous system diseases such as Huntington's and Alzheimer's diseases from polyunsaturated fatty acids (PUFAs). Being acquired by US company Amarin |
| **Marine Biotechnology Products**<br>125 Ramsden Square, Barrow-in-Furness, Cumbria<br>LA14 1XA | | Registered at Companies House but no further information available yet |

### TABLE 20: CONT

| COMPANY | CONTACT | SECTOR |
|---|---|---|
| **NCIMB Ltd**<br>23 St Machar Drive, Aberdeen AB24 3RY | Ian Garner, Gordon McFarlane<br>T: 01224 273332<br>F: 01224 272461<br>enquiries@ncimb.co.uk<br>www.ncimb.co.uk | Commercial arm of the National Collection of Industrial, Marine and Food Bacteria, providing research and consultancy in microbiology; part-funded by BBSRC. |
| **Novacta Biosystems Ltd**<br>Innovation Centre, University of Hertfordshire, College Lane, Hatfield, AL10 9AB | Fiona Marston, Brian Rudd, Mike Dawson<br>T: 01707 281100<br>mail@novactabio.com, brian.rudd@novactabio.com | Drug discovery & development company using pathway engineering and chemistry to optimise the activity of natural products for the treatment of infectious diseases; though not exclusively focused on marine biotechnology, marine organisms are one source of compounds for the company. |
| **Plymouth Marine Applications**<br>Prospect Place, The Hoe, Plymouth PL1 3DH | Carole Llewellyn<br>T: 01752 633 100<br>F: 01752 633 101 | Commercial arm of Plymouth Marine Laboratory; currently working on characterisation and exploitation of marine chlorophylls and carotenoids (Small Business Research Initiative) |
| **Remedios Limited**<br>MacRobert Building, 581 King Street, Aberdeen AB24 5UA | Ian George Managing Director<br>T: 01224 274255 F: 01224 274256 www.remedios.uk.com | Use of marine microbial *lux* gene as basis for land contamination sensor and remediation monitor; spin-out from University of Aberdeen |
| **SAMS Research Services Ltd**<br>Dunstaffnage Marine Laboratory, Oban, Argyll, PA34 4AS | Prof Graham Shimmield<br>T: 01631 559000<br>F: 01631 559001 | Provides all the commercial services (including billing) for Scottish Association of Marine Sciences' (SAMS) scientific activities. |
| **SEAS Ltd**<br>c/o Dunstaffnage Marine Laboratory, Oban, Argyll, PA34 4AS | Mr J Blackstock<br>T: 01631 566877<br>F: 01631 564124<br>seas@wpo.nerc.ac.uk | Private consultancy and research company based at Dunstaffnage Marine Laboratory, specialising in analysis of marine benthic samples, polychaete taxonomy, benthic community structure and adaptive responses to stress; recently absorbed into SAMS Research Services Ltd. |
| **X-Gnat Labs Limited**<br>Unit 11, Beta Centre, Stirling Innovation Park, Stirling FK9 4NF | T: 01786.442006<br>F: 01786.442006 | X-Gnat specialises in insect and organism repellents, based on environmentally friendly materials; involvement in marine biotech is through being a partner with Grant Burgess of HWU on a project to develop an anti-fouling paint using marine microbial extracts. |

*<u>Note:</u> Plymouth Marine Laboratories is about to spin out two new companies[80], so that this number may change. Two companies are profiled below, since they illustrate the combination of public and private funding that is assisting start-ups in this area. The strategies of both companies are similar: to establish one stream of activity that is income-generating (contract work in shellfish toxin analysis for Integrin and in rapid screening for Aquapharm) whilst investigating novel bioactives from proprietary collections of marine microbes.*

80 pers. comm. D Robins 2004

## CASE STUDIES: AQUAPHARM BIO-DISCOVERY AND INTEGRIN ADVANCED BIOSYSTEMS

***Aquapharm Bio-Discovery** Ltd was founded in 2000, after Andrew Mearns Spragg, a PhD at Heriot-Watt University, had gained a Royal Society of Edinburgh-Scottish Enterprise Fellowship, which he continued at St Andrews University.*

*The company was founded to commercialise antibacterial molecules from marine organisms; in the process of developing this, a faster assay and screening system was developed and new anti-oxidant and aquaculture feed pigments were discovered. Aquapharm also has its own culture collection.*

*The company has moved from Edinburgh to ECMB Oban because of favourable costs and facilities that allow the business and research sides of the company to co-locate.*

*Aquapharm has obtained funding from private sources and from public endowments, including the SE/RSE Enterprise Fellowship, SMART: Scotland funding (end-2001), NESTA (£50,000 in January 2003 and follow-on) and a BBSRC CASE award. Andrew has followed the strategy of getting potential licensees on-side by undertaking co-development projects. Aquapharm used the CONNECT Springboard conference in Scotland to begin the process of gaining almost £1.5 million in external funding, due to complete in 2004.*

***Integrin Advanced Biosystems** Ltd was founded in 1999, effectively as a spin-out from SAMS at Dunstaffnage. The company has two different streams of activity, drug discovery, focusing on anti-inflammatories from marine organisms & monitoring seafood for planktonic toxins.*

*Early funding included a contract for PharmaMar SA, other service contracts and a Eureka grant of £170,000 to develop novel bacterial assays. Integrin has been active in seeking appropriate support grants from Argyll & the Islands Enterprise, receiving almost £47,000 for business development, product development and training between 2001 and 2003.*

*Revenues in 2001 were £250,000 from services and contracts and, by 2002, total capital raised approached £950,000. Integrin is now the UK leader in shellfish toxin testing and received the Pfizer Award for Innovation in Life Sciences in 2003 as recognition of this. Integrin is also working on a CRAFT project for European SME shellfish producers on detoxification of harvested product.*

*In January 2003 the company was successful in gaining £330,000 from a combination of HIE Ventures, Argyll & Islands Enterprise (£71,000) and private funds. It has been seeking up to £5 million in external funding.*

# ANNEX B: RESEARCH ACTIVITY

## TABLE 21: MARINE BIOTECHNOLOGY RESEARCH ACTIVITIES IN HEIS AND ORGANISATIONS IN ENGLAND

| HEI | ACTIVITIES (HISTORIC AND CURRENT) |
|---|---|
| **Aston University**<br>Chemical Engineering and Applied Chemistry, | Investigating the use of porous marine-origin structural biomaterials from corals, sponges and sea-urchins in the production of artificial cornea for keratoplasty techniques |
| **Birmingham, University of**<br>School of Biological Sciences | The molecular and cellular basis of primary adhesion by *Enteromorpha* spores (Marine Biofouling Thematic Programme MBTP – NERC 1995-1998); Marine Biofouling, especially in relation to the control of algae which foul ships; core member of EU NoE Marine Genomics; Microbial interactions in natural assemblages, N-acylhomoserine lactones and *Ulva* zoospore adhesion (Marine & Freshwater Microbial Biodiversity programme M&FMB – NERC 2000-2005) |
| **Brighton, University of**<br>Faculty of Science & Engineering | Working on glycine betaines and other marine-derived betaines for cryopreservation of biological systems |
| **Bristol, University of**<br>School of Chemistry,<br>School of Biological Sciences<br>Biogeochemistry Research Centre | Prokaryotic ether lipid membranes, Picocyanobacteria communities & Novel molecular markers for sub-sea microbes (M&FMB); Bacterial populations in ocean sediments, palaeo-oceanography; synthesis of marine natural products (EC-funded 1997-2000) |
| **British Antarctic Survey**<br>Cambridge | Genomic and metagenomic studies on Antarctic organisms, including extremophilic cyanobacteria and microbial communities. Exploitation will however be constrained by bioprospecting aspects of Antarctic Treaty. Member of EU NoE Marine Genomics |
| **British Oceanographic Data Centre**<br>University of Liverpool | Central data repository and distributor for M&FMB project results |
| **Buckingham, University of**<br>Clore Laboratory for Life Sciences | Biofouling |
| **Cambridge, University of**<br>Dept of Chemistry | In the past has been a recipient of EPSRC grants for total synthesis of interesting marine bioactives including swinholide A, marine polyketides, squalestatins, scytophycin, aplyronine, bistheonellide and discodermolide |
| **East Anglia, University of**<br>School of Environmental Sciences | Marine microbial ecology, Biogenic production of trace gases of atmospheric importance in marine waters. Biological oceanography, seaweed physiology and trace gas production; Viruses and biogeochemical cycling, Sulphur compounds and viral infection of phytoplankton & Virus-host dynamic during *Emiliania huxleyi* bloom (M&FMB); M&FMB Programme Science Co-ordinator for NERC |
| **Essex, University of**<br>Dept of Biological Sciences | microbial interactions and the functioning of microbial consortia, application of microbial diversity, oil bioremediation, extremophiles esp. halophiles and their biotechnological applications; Novel *Archaea* in coastal marine sediments, Culture methods for novel marine and estuarine microbes (M&FMB with University of Reading); structure and function of complex microbial communities in aquatic systems and microbiology of polluted environments; atmospheric trace gas exchange by aquatic bacteria, cycling of C, N & S in coastal and Antarctic regions, ecology of aquatic and sedimentary organisms |

### TABLE 21: CONT

| HEI | ACTIVITIES (HISTORIC AND CURRENT) |
|---|---|
| **Hull University** | algal functional group ecology, techniques for monitoring algal communities, morphological variation and speciation of fucoid algae, general intertidal ecology and conservation biology; fisheries and biological oceanography and behaviour of krill; member of EU NoE Marine Genomics |
| **Kent, University of**<br>Applied & Environmental Microbiology Group | Studying novel biotechnological applications provided by bacteria from the deep sea. Research collaborations with groups in Spain, France, Germany, Hungary, Japan, Indonesia, Greece, Norway, Italy, Portugal; Sedimentary actinomycetes (diversity and sampling methods), *Pseudonocardiae* from marine sediments & Marine *Micromonosporae* diversity (M&FMB, with Newcastle); Abyssomycins (with Eberhard Karls Universität Tübingen Germany and University of Newcastle-upon-Tyne) |
| **King's College London** | Surface active proteoglycan secretions from marine invertebrates and their role in modulating biofouling |
| **Lancaster University**<br>Institute of Environmental and Natural Science | Trace metal metabolism and cycling in freshwater and marine environments (M&FMB with Marine Biological Laboratory Copenhagen University Denmark, Lucas Heights Science & Technology Centre Australia and University of Aberdeen); high resolution analysis of trace metal-sediment interactions |
| **Leeds, University of**<br>Dept of Microbiology | Molecular biology of freshwater cyanobacteria & Biofilm-disrupting compounds from marine bacteria (M&FMB) (Biofilm work with Heriot-Watt) |
| **Liverpool, University of**<br>School of Biological Sciences<br>Port Erin Marine Laboratory<br>IRC in Surface Science | Analysis of the structure and activity of bacterial populations in natural soil, sediment and water environments; development of molecular and DNA-based methods to profile bacterial communities; dynamics of microbial communities; gene fluxes and gene function in natural environments; Chemisorption studies related to reactive organic film growth; lysogenic phages in freshwater bacteria (M&FMB); commercial activity: Environmental Research and Consultancy's Marine Services |
| **Manchester, University of**<br>**UMIST** Dept of Chemistry | Microbial adhesion and biofilm formation. Interbacterial adhesion in aquatic biofilms; Cytokine resuscitation of actinomycetes (M&FMB) |
| **Marine Biological Association**<br>Plymouth | Active in NERC's MBTP programme: marine viruses; induction of barnacle larval settlement, settlement pheromones; modulation of marine invertebrate larval settlement and metamorphosis by eicosanoids; can bacterial metabolism self-regulate attachment to surfaces?; a partner in the EU NoE Marine Genomics; Viruses and biogeochemical cycling, Gene transfer via marine bacteriophages, Virus-host dynamics in *Emiliania huxleyi* blooms, Molecular biology of freshwater cyanobacteria, Sulphur compounds and viral infection of phytoplankton, Photosynthesis genes in marine viruses & Exploitation potential of marine viruses (M&FMB) (Photosynthesis genes with University of Warwick and MBA) |

### TABLE 21: CONT

| HEI | ACTIVITIES (HISTORIC AND CURRENT) |
|---|---|
| **Newcastle-upon-Tyne, University of**<br>Centre for Coastal Management Dove Marine Laboratory<br>School of Marine Science and Technology<br>Centre for Molecular Ecology<br>School of Civil Engineering and Geosciences<br>School of Biology<br>Agricultural & Environmental Science<br>Postgraduate Institute, Newcastle Research Group | particular strengths in tropical and temperate marine biology; owns a research vessel. Departmental specialisms: environmental signal transduction in marine organisms; marine ecosystem dynamics; well-established marine engineering department; marine invertebrate reproduction and development, esp. larval settlement; marine biofouling/antifouling; invasive species; ecotoxicology (esp. endocrine disruption); seasonal variation of antifouling activities of marine algae from the Brittany Coast; research in behavioural ecology, ecophysiology, and biofouling, temperate and tropical ecosystems; Novel rhodococci, streptomycetes and actinomycetes from the deep sea (characterisation and exploitation), Diversity of sediment actinomycetes, Microbial N2 fixation, Diversity of diazotrophs in the Arabian Sea, Models for screening microbial biodiversity & Bioactive screening on a chip (M&FMB); microbial ecology and environmental microbiology, geomicrobiology, biodegradation of hydrocarbons, Microbiology of biogeochemical cycles; Abyssomycins (with Eberhard Karls Universität Tübingen Germany and University of Kent & Canterbury); member of EU NoE Marine Genomics |
| **Nottingham, University of**<br>Centre for Biomolecular Sciences | Microbial interactions in natural assemblages & Natural antifoulants from actinomycetes (M&FMB) |
| **Oxford, University of**<br>Dept of Zoology | marine taxonomy and distribution; Dispersal of free-living microbial species & Biodiversity and ubiquity of *Gymnamoebae* and *Cercozoa* (M&FMB); member of EU NoE Marine Genomics |
| **Plymouth Marine Laboratory** | an independent charitable company limited by guarantee, affiliated to NERC; Core research in estuarine and coastal function and health, scaling biodiversity and the consequences of change and microbially-driven biogeochemical processes, exchanges and controls; marine viruses, including those of microalgae and bacteria; cell signalling and nutrient uptake in biofilms and biofouling; bacterial-trace metal interactions, Characterisation of MeBr degraders, Bacteria-trace metal interactions, Virus-host interactions in *Emiliania huxleyi* bloom, Sulphur compounds and viral infection of phytoplankton, Molecular biology of freshwater cyanobacteria, Photosynthesis genes in marine viruses, Novel enzymes from marine viruses & Natural antifoulants from actinomycetes (M&FMB) (Photosynthesis genes with University of Warwick and MBA, Natural antifoulants with University of Nottingham)<br>Commercial activity: Plymouth Marine Applications - Characterisation and exploitation of marine chlorophylls and carotenoids (Small Business Research Initiative) |
| **Plymouth, University of**<br>Marine Algal Research Group<br>Dept of Environmental Science | marine algae and environmental pollution; cellular responses to stress in algae; commercial and applied activity in seaweed and polyculture within the Centre for Applied Plant Research; Bromine cycling, Microbial interactions in natural assemblages, Bacteria-trace metal interactions & Diatom pigments (M&FMB) |

### TABLE 21: CONT

| HEI | ACTIVITIES (HISTORIC AND CURRENT) |
|---|---|
| **Portsmouth, University of**<br>School of Biological Sciences<br>Institute of Marine Sciences | Marine fungi; production of PUFAs by thraustochytrids; n-substituted imides as antifoulants; *Mytilus edulis* phenoloxidase; international collaborations on bioactives with Quimper and Concarneau, France; marine wood borers, Protection of wood in the sea, Impact of biocides used in wood protection on marine invertebrates, bivalve larvae, mangrove ecology in relation to the utilisation and the breakdown of wood; taxonomy and systematics of Brown Algae. Fouling/antifouling studies, pollution studies; the role of bacterial exopolymers in marine fouling and deterioration of steel surfaces: (MBTP); can bacterial metabolism self-regulate attachment to surfaces?; ecotoxicology and ecophysiology of fish and marine invertebrates, Fish endocrinology, Sensory biology of fish and invertebrates; environmental and endocrine control of reproduction in marine invertebrate, Ecotoxicology, Effects of pollutants and other human impacts (bait collection) on invertebrate reproduction, the role of chemical signalling in marine invertebrates. |
| **Queen Mary, University of London** | Nitrogen transformations in estuarine and coastal sediments; marine and estuarine benthic ecology and conservation |
| **Reading, University of**<br>School of Animal and Microbial Sciences | Environmental Systems Science Centre PhD / MPhil (Departmental specialism includes Marine Science); Characterisation of non-extremophilic estuarine organisms & Novel *Archaea* in coastal marine sediments (M&FMB) |
| **Royal Holloway, University of London**<br>School of Biological Sciences | Parasitology and aquatic toxicology: Ecology and epidemiology of parasites in aquatic and terrestrial hosts. Development of fish biosensors for early detection of pollutants in water. Fish and other aquatic host-parasite systems as indicators of water quality and environmental stress; ecology and physiology of aquatic, intertidal and marine invertebrates, especially amphipod crustaceans; adaptations to life in extreme environments; induction of barnacle larval settlement: the nature and perception of settlement pheromones (MBTP) |
| **Sea Fish Industry Authority**<br>Hull | supports projects in improving sustainable seafish and shellfish farming, nutrition (possible role for microalgae, for example), microalgal-related shellfish toxins; seafood waste as composts; fish processing technologies and new product development |
| **Sheffield, University of**<br>Biological and Environmental Systems Group | Applied research on extremophiles in culture, to investigate their physiology and biochemistry and make use of these for industrial processes, including new bioactives, halophiles, piezophiles, thermophiles; bioactives and hydrogen from marine cyanobacteria; solvent-tolerant marine microbes |
| **Southampton, University of**<br>Southampton Oceanography Centre, School of Ocean & Earth Science<br>The George Deacon Division for Ocean Processes, SOC | biomarkers, biogeochemistry of deep-sea animals, marine biofouling, carbon cycle, biosensors & chemical sensors; remote sensing methodology; effects of predation and nutrient recycling by protozoa on the development of communities of marine biofouling organisms (MBTP); a multidisciplinary research group of biological, physical and chemical oceanographers; The Oceanography Centre also hosts the Inter-Agency Committee on Marine Science and Technology, T:02380 596611, www.marine.gov.uk; physiological and environmental ecology of marine microalgae, phytoplankton, benthic microalgae, coccolithophore biology, physical-biological interactions at fronts, biostabilisation of intertidal sediments; larval biology of marine invertebrates, bathyphilic environments including hot vents and cold seeps, Antarctic invertebrates; Marine biogeochemistry of trace metals, carbon, and nutrients & Molecular ecology, physiology and genetic diversity of phytoplankton (M&FMB), functional genomics of bioluminescence in marine dinoflagellates; core member and partner of EU NoE Marine Genomics |

### TABLE 21: CONT

| HEI | ACTIVITIES (HISTORIC AND CURRENT) |
|---|---|
| **Surrey, University of**<br>Microbial Physiology & Ecology Group | Research includes bioproduct physiology, microbe/surface interactions, microbe-microbe signalling and bioelectronics (interface between biosystems and electronics), advanced fermentation technology for production of bioactives, ecosystem function in attachment/biofilms [not clear if marine]; development of microarrays for characterising novel deep sea and coastal streptomycetes (collaboration with M&FMB project at University of Newcastle) |
| **University College London**<br>Royal Free Hospital School of Medicine<br>Dept of Chemistry & Molecular Biology | Working with Prof A Lloyd (Brighton) and Destiny Pharma Ltd on alginates and chitosans for tissue engineering scaffolds<br>Phylogenetic analysis of biodiversity in deep marine and hydrothermal vent biotopes |
| **Warwick, University of**<br>Dept of Biological Sciences | Cyanobacteria; phage ecology and exploitation; a partner in the EU NoE Marine Genomics; Bromine cycling, Characterisation of MeBr-degraders and assessment of potential as biocatalysts, Community structure of picoeukaryotes, Photosynthesis genes in marine viruses & Gene transfer via marine bacteriophages (M&FMB) (MeBr project with PML and University of Waikato New Zealand, picoeukaryote project with Station Biologique Roscoff France) |
| **Wolverhampton, University of** | Subcellular membrane transport processes studied in marine fungi; specialisms include gastropod oxidases [not clear if marine]. |
| **York, University of** | marine biodiversity conservation, coral reefs, coastal management, tourism sustainability, marine reserves, threatened species, fishery management; pigments from diatoms (M&FMB 2004) |

### TABLE 22: MARINE BIOTECHNOLOGY RESEARCH ACTIVITIES IN HEIS IN SCOTLAND

| HEI | ACTIVITIES (HISTORIC AND CURRENT) |
|---|---|
| **Aberdeen, University of**<br>Aberdeen Institute for Coastal Science & Management<br>Dept of Zoology<br>Marine Natural Products Lab<br>Dept of Chemistry<br>Oceanlab<br>Dept of Molecular and Cell Biology Institute of Medical Sciences | ecology, physiology and *in situ* behaviour of deep-sea fauna; fundamental and applied studies in a wide range of ecosystems, intertidal to deep Arctic; marine natural products and marine biotechnology: novel fatty acids from marine algae, novel pharmaceutical agents from sponges; systems development: engineering of deep ocean instrumentation packages; lab studies on functional morphology and physiology using material retrieved by trap or trawl from the deep sea; work in MBTP; Viruses and plankton blooms & Trace metal cycling (M&FMB); spin-out Remedios, environmental biosensors; molecular analysis of marine bacterial communities.<br>NCIMB (National Collections of Industrial, Food and Marine Bacteria) and NCIMB Ltd, the commercialisation activity relating to this, are hosted at Aberdeen. |
| **Edinburgh, University of** | microbial genomics and genotyping applied to foraminifera and other marine microbes |
| **Fisheries Research Services**<br>Marine Laboratory, Aberdeen | fish diseases and disease diagnosis using molecular methodology; focus on diseases of turbot; biodiversity, microbiology, benthic studies and plankton; taxonomy of flatworm fish parasites using molecular methods; sea lice; bacterial and viral diseases of fish; viruses and phytoplankton blooms (M&FMB) |

### TABLE 22: CONT

| HEI | ACTIVITIES (HISTORIC AND CURRENT) |
|---|---|
| **Glasgow, University of**<br>Institute of Biomedical and Life Sciences<br>Dept of Civil Engineering<br>UMBS Millport<br>Glasgow Marine Technology Centre | work with Strathclyde on a library of natural materials, including some marine samples; Biofouling-resistant surfaces, functional biomimetics (including MAST project on antifouling), underwater sensors and reduced environmental impact of marine technologies; biodiversity, microbiology and benthic studies |
| **Heriot Watt University**<br>Centre for Marine Biodiversity and Biotechnology, School of Life Sciences<br>Dept of Chemistry, School of Engineering and Physical Sciences | marine biofouling, bacterial cell signalling, bioreactors and general aspects of marine biotechnology. Engaged in research aimed at the industrial and medical applications of marine bacteria and fungi. In particular interested in cell-cell signalling in marine gram-positive bacteria and its effect on the synthesis of antimicrobial compounds; production of bioactive compounds by marine fungi; chemical ecology of seaweed surface: antifouling activity of Epiphytic bacteria from intertidal and subtidal seaweeds (MBTP); Biofilm-disrupting compounds & Cell signalling system regulating antibiotic and pigment production (M&FMB); fluidisation systems; solid state fermentation; moisture in particulate systems; novel bioreactor technology; recipient of an award from the Royal Society for work on novel reactors for marine bacteria; project funding comes from EPSRC, Scottish Hospital Endowments Research Trust, BBSRC, Pfizer, SmithKline Beecham and NERC; fish diseases, vaccine development, marine bioactives as antibiotics; fish physiology, new treatments for sea lice |
| **Napier University**<br>School of Life Sciences | Development of microbial biosensors for pollution and pollutant assessment, with prospects for commercialisation, biodiversity, plankton. Sources of funding: EU, Scottish Enterprise |
| **Royal Botanic Garden** | Diatom taxonomy, preservation of CCAP's voucher material for marine microbial strains (Marine algal characterisation and exploitation 'MACE' M&FMB with SAMS) |
| **St Andrews, University of**<br>Gatty Marine Laboratory | Chemical and structural characterisation of invertebrate non-fouling surfaces; biofouling; planktonic barnacle larval distribution; Immune systems of crustacea; Aquapharm is a Gatty spin-out. |
| **SAMS Dunstaffnage Marine Laboratory** | fjordic systems, ocean margins, measuring and modelling change using sea sensors and information technology; Chemical and structural characterisation of invertebrate non-fouling surfaces & Surface active proteoglycans from marine invertebrates (MBTP); marine bacteria as a source of novel biosurfactants and bio-emulsifiers; The Culture Collection of Algae and Protozoa (CCAP-Marine); Marine algal characterisation and exploitation 'MACE' (M&FMB); Marine malcroalgal pathogens – phylogenetic affinities (with Dept of Biology University of Konstanz Germany, CNRS-Station Biologique Roscoff France and CNRS-Université Pierre et Marie Curie Roscoff) |
| **European Centre for Marine Biotechnology** | To be opened in June 2004 |
| **Stirling, University of**<br>Dept of Biological Sciences | Diversity of diazotrophs in the Arabian Sea (microbial N2 fixation) (M&FMB) |
| Machrihanish Marine Environment Research Laboratory | mariculture-related research |
| **Strathclyde, University of**<br>Strathclyde Institute for Drug Research | in collaboration with Glasgow in the PharmaLinks initiative; maintains and works on over 6,500 natural extracts in the Natural Products Library, of which a few dozen are marine from overseas |

### TABLE 23: MARINE BIOTECHNOLOGY RESEARCH ACTIVITIES IN HEIS IN WALES

| HEI | ACTIVITIES (HISTORIC AND CURRENT) |
|---|---|
| **Aberystwyth, University of Wales**<br>Institute of Biological Sciences | cytokine resuscitation of 'unculturable' actinomycetes (M&FMB) |
| **Bangor, University of Wales**<br>School of Ocean Sciences, Centre for Applied Oceanography, Marine Science Laboratories | microbial communities in biofilms, bioremediation, marine microalgae, reef ecology; a partner in the EU NoE Marine Genomics |
| **Cardiff, University of Wales**<br>Cardiff School of Biosciences, Cardiff School of Earth, Ocean and Planetary Sciences | A partner in the EU NoE Marine Genomics; Isobaric *in situ* sampling and collection device, Novel molecular markers for sub-sea microbes, Isolation of unculturable bacteria & Prokaryotic ether lipids (M&FMB) |
| Wound Healing Research Unit, Cardiff Medicentre, Heath Park, Cardiff CF14 4UJ | Using alginate derivatives in studies of wound healing; carrying out confidential commercial developments utilising marine-origin materials |
| **Swansea, University of Wales**<br>Singleton Park, Swansea, SA2 8PP<br>T: 01792 205678, F: 01792 295618 | Modulation of marine invertebrate larval settlement and metamorphosis by eicosanoids with Dr A. Clare (Marine Biological Association) MBTP research |

### TABLE 24: MARINE BIOLOGY AND BIOTECHNOLOGY ACTIVITIES IN NORTHERN IRELAND

| HEI | ACTIVITIES (HISTORIC AND CURRENT) |
|---|---|
| **Belfast, Queen's University**<br>School of Biology and Biochemistry, Depts of Pharmacy & Chemical Engineering | BSc in Marine Biology, PhD in Marine Biology including Molecular Ecology and Evolution, Molecular Microbiology & Marine Systems; projects in bioremediation using macroalgae and biomonitoring; Carapacics is a QUBIS spin-out in chitin products |
| **Ulster, University of**<br>School of Biological and Environmental Sciences, Coleraine | offers Marine Science BSc (Hons) with Marine Biotechnology; has an Applied Microbiology and Biotechnology group working on bioremediation and biochemistry, stable marine-origin enzymes and physiology of marine organisms |
| **Centre for Innovation in Biotechnology** | joint venture between QUB and University of Ulster Coleraine |
| **Department of Agriculture and Rural Development for Northern Ireland** | Scientific studies on marine and freshwater fisheries and the environment |

# ANNEX C: PARALLELS WITH DEVELOPMENTS ON NON-FOOD CROPS

The challenge for the marine biotechnology community in capitalising on marine resources is somewhat similar to that faced by those researching and developing non-food uses of crops. This sector faces static investment in R&D and a need to enhance understanding of the capacity for contribution to UK economy, amongst policy, academic and industry communities. A report published at the beginning of 2004[81] recommends

- investment in bio-refining technology platforms (equivalent to bioreactors and bioprocessing for marine biotechnology)
- collaboration across the range of biosciences
- promoting the use of non-food crops for pharmaceuticals and specialist materials
- stimulating the application of venture capital to commercialisation
- maintaining research funding to ensure world-class performance
- developing statistical and other databases to support policy formation.

The report points out the growing demand for products and raw materials from renewable sources to replace petrochemical-based materials; this is also one target for marine biotechnology (microalgal or microbial surfactants, for example). Bioremediation is another target. Several of the recommendations for action are relevant to marine biotechnology.

The recommendations that seem most relevant to the marine biotechnology community at the moment, and that might be successfully transferred, are highlighted below:

- develop an integrated UK strategy through the medium of a working group
- develop technology roadmaps for different application areas, so that their specific needs are highlighted
- promote R&D investment and academic research in bio-processing, through a new HEI-industry collaborative programme
- secure full UK involvement in the design and development of European initiatives
- establish a programme of demonstration projects in containment culture for high-value outputs
- fund commercialisation studies for each demonstration project
- promote and support bioscience technology fairs
- encourage interchanges between investment and industrial companies by secondments
- foster links between investment organisations and HEI commercialisation units
- ask OST to urge BBSRC to explore the potential for cross-RC initiatives with MRC, EPSRC, NERC
- commission a statistical study that examines and differentiates between the different application areas and sectors of UK industrial biotechnology.

---

[81] *Prospecting Bioscience for the future of non-food uses of crops* January 2004 A McMeekin, M Harvey *et al.* for the Government Industry Forum on Non Food Uses of Crops

# ANNEX D: POTENTIAL SOURCES OF FUNDING AND SUPPORT FOR MARINE BIOTECHNOLOGY

The UK Government sees uptake of innovation as a critical element in stimulating UK manufacturers to match productivity levels in France, Germany and USA. *Investing in Innovation* [82] has announced additional investments by 2005-2006 in skills base (£100 million pa), science and engineering research (£400 million pa), equipment and capital spend (£100 million pa), the HEIF (to reach £90 million pa) and the PSRE Fund (£15 million extra), from which marine biotechnology should aim to benefit.

More specifically, there are relevant cases of capital expenditure (or estimates) to take into account in estimating costs of new initiatives. In the UK, these are the establishment of the European Centre for Marine Biotechnology (ECMB) at SAMS, Dunstaffnage and the proposed Plymouth MSTP.

- Including ECMB and related renovation of existing facilities, a total budget of £8.3 million has been spent at SAMS, including a contribution from EU funds of approximately £2.4 million and support from Highlands & Islands Enterprise, Argyll & the Islands Enterprise, the Scottish Executive and commercial lenders.
- In Plymouth, the very preliminary estimate for the establishment of the MSTP is £30-£50 million, based on the average level of investment in the UK's 10 largest Science Parks (£60 million) and expenditure on the first stages of the Tamar Science Park of just over £13 million.[83] The project has now moved onto a more detailed costing stage.

Elsewhere, various comparator figures for support of marine biotechnology programmes can be garnered from different sources:

- The budget of the Marine Institute **Ireland** and related institutions was Ir£13.5 million in 1998 (latest figures easily obtainable); a six-year plan was established in 2000 for marine research and technology development and innovation, of which the project budget was approximately £15 million (pounds sterling).
- Even fragmentary data for state and national support programmes in marine biosciences in **USA** suggest that over £300 million has been spent in the last 15 years; recently, a virtual centre of excellence in biomedical and marine biotechnology has been established in Florida, with state, national and HEI support totalling over £6 million[84]
- In **Australia**, the main effector of the Oceans Policy in biosciences is the Australian Institute for Marine Science (AIMS), with a total budget for 2004-2005 of about £11 million, about 25% from the sale of goods and services (contract projects and licensing); the departmental spend for the marine biotechnology group for 2003-2004 was about £2.7 million
- Current figures for **Japan** are difficult to find; however, the Marine Science and Technology Center's budget for marine engineering and sciences was £190 million in 2002, the Marine Biotechnology Institute's start-up investment from a public-private partnership between1988-1998 was almost £125 million, plus

[82] Investing in Innovation. A Strategy for science, engineering and technology July 2002, DTI, HM Treasury and DfES (Dept for Education and Science)

[83] Feasibility Study for the development of a marine science and technology (MST) cluster in Plymouth Final Report April 2003, GHK & BMT, for the City of Plymouth, page 51

[84] see http://www.floridabiotech.org/

significant funding from state R&D programmes, and in 2000 Takara Shuzo established Dragon Genomics Center, with 20% (approx £7 million) of its budget devoted to marine genomics and the search for useful genes and products.

For funding of specific marine biotechnology programmes, and at a more local level, the most accessible source is the EU's Framework Programme 6 (FP6). This has funded three relevant programmes:

- BlueBioNet, the Platform for European Blue Biotechnology, which is aimed at converting traditionally-structured maritime regions into European Knowledge Regions for applied biotechnology and has the goals of developing a number of commercial and international R&D collaborations by December 2005[85]
- Two Networks of Excellence with marine biodiversity themes, including one on Marine Genomics.

The Fore*sight* Marine Panel has noted that research funding may be available from the USA.[86] There are potential contributions of marine biotechnology to research, development and applications in diagnosis and management of biohazards and bioterrorism that also make it worthwhile exploring opportunities for funding within, for example, the BioShield programme, signed by the US President in July 2004[87].

## *Funding Virtual Institutes*

Apart from conventional technology transfer functions in UK HEIs, there are several organisations that seek to add value to HEI resources and expertise by helping businesses and their advisors find the best mix of skills and facilities across institutions rather than within. Examples of two of these are given below, Scottish Biomedical and i10, since they could well provide models or best practice for similar efforts in marine biotechnology development and exploitation.

---

85 *pers. comm.* G Shimmield 2004

86 *Marine Technology, report of the eighth Foresight Seminar, 13 May 1999*, with reference to the Department of Defense's Office of Naval; Research, see http://www.ma.hw.ac.uk/RSE/govt_responses/commercialisation/seminar_reports/foresight/f08may99.pdf

87 see http://www.whitehouse.gov/bioshield/

### CASE STUDIES: SCOTTISH BIOMEDICAL & i10

*__Scottish Biomedical__ was founded in 1994, acting as marketer, broker, project-former, project manager and negotiator on behalf of the biomedical science functions of six Scottish Universities, creating collaborative teams across disciplines to answer the specific needs of clients. It has had notable international successes with Japan, facilitating the establishment of the Kyorin Research Scotland Laboratories, the YRING Institute in Glasgow and a long-term cross-institute project for the Kowa Company. It has now established its own laboratories, gaining a SMART: Scotland award in 2000 for human tissue techniques that ensure stability of messenger RNA for gene analysis research. Scottish Biomedical's success in attracting an estimated £40 million in biomedical funding to Scotland has been recognised by the Biotech Scotland Award in 2002 and a SMART Achievement Award in 2003. Turnover in 2002-2003 was £5 million, with profits of over £125,000, and the Foundation completed a transition to a fully-independent company as a result of a leveraged management buy-out in 2002.*[88]

*__i10__, a collaboration between 10 HEIs in East of England, has received c. £3 million to help fund inter-institution projects that respond to regional and industrial sector needs. The i10 network is aimed at businesses and their advisors, and is a 'front-end' that then matches appropriate resources across the region's HEIs. This is co-ordinated through the University of Cambridge and served by a web-site, which also aids networking and information-finding. i10 is working on a standardised data-base of academic resources and expertise in the region to help the process. The i10 structure could provide a model for development of a marine biology, bioscience and biotechnology resource database and collaboration network, essentially web-based with a funded co-ordination centre at a relevant establishment.*[89]

## *Funding Sector Support and Interest groupings*

Sector support programmes have been quite successful in UK, in particular **Bio-WISE**, which targets the use of biotechnology in waste management, and the **National Non-Food Crops Centre** (NNFCC), which services farmers, processors, manufacturers and researchers in a wide range of unconventional non-food sectors. These are models for an interest grouping in marine biotechnology, as well as useful links for enhancing exploitation and partnering (for example, making use of the Rothamsted International Biomarket conferences.[90]) These are profiled below in more detail.

### *Investing in commercialisation and economic development*

As part of its re-appraisal of its role in supporting innovation and economic development, the UK Government has established a number of innovative programmes aimed at

88 see http://www.scottish-biomedical.com, http://www.ideas21.co.uk/317, http://www.scotland.gov.uk/news/2000/10/se2767.asp and other related sites

89 see http://www.i10.org.uk

90 see http://www.biomarket.rothamsted.ac.uk/index.php

starting-up and maintaining new businesses, which are relevant to marine biotechnology.[91] These include the DTI's Enterprise Capital Fund (ECF) programme, currently undergoing a pilot scheme, Pathfinder ECF, with up to £2 million of public and private funds.[92] The existing Enterprise Investment Scheme (EIS) will be maintained, extended to allow groups of business Angels to form funds - recent estimates are that the UK's angel funding may be as much as £500 million - £1 billion a year, 75% of this below £100,000 and 8% above £250,000[93], well within the range needed by embryo marine biotechnology companies. The Venture Capital Trusts scheme will also be maintained, to allow formation of funds for investment of more than £1 million in SMEs.[94]

## Government-sponsored mechanisms for scientific and economic development

### NERC programmes

NERC is supporting marine bioscience in 3 programmes for the period 2000-2005. These include:

- the M&FMB programme, cost £7 million (including a research cruise and SBRI grants for proof-of-concept and exploitation projects)[95]; this is now complete
- the Environmental Genomics Programme, cost £16.5 million, in which 4 of 28 projects involve marine or aquatic genomes[96]; there should be a third round of funding in this
- the Marine Productivity Programme, cost £6.5 million, which includes biology, modelling, behaviour, ecology, molecular identification and development of marine plankton.

---

[91] Science and innovation investment framework 2004-2014 July 2004 HM Treasury, DTI and DfES

[92] see http://www.sbs.gov.uk/default.php?page=/financegap/default.php

[93] Bridging the finance gap: a consultation on improving access to growth capital for small businesses April 2003, HM Treasury and DTI's Small Business Service

[94] Bridging the finance gap: a consultation on improving access to growth capital for small businesses April 2003, HM Treasury and DTI's Small Business Service

[95] see http://www.nerc.ac.uk/funding/thematics/mfmb/

[96] see http://www.nerc.ac.uk/funding/thematics/envgen/

### CASE STUDIES: BIO-WISE & NNFCC

***Bio-Wise***[97] *began in 1996 as Biotechnology Means Business, a DTI-funded programme aiming to support the increased use of biotechnology in British industry. Bio-Wise itself was launched in 1999, also funded by DTI, at £13 million over four years, to continue embedding the use of biotechnology for environmental management, often in relatively low-tech circumstances (such as reduction in the polluting power of fats and oils in fast-food restaurants, or providing bioremediation for dying and tanning effluents). 25% of eligible costs are covered, grants are in the range £25,000-£250,000. The programme has been very successful in creating case studies and bringing together research, applications, environmental consultants, system and process designers and businesses in a range of industrial sectors. This is all relevant to any effort to create a UK marine biotechnology community and, in particular, increased interaction between companies with a need for technological solutions to problems and HEIs or institutes with answers. The web-site for the Bio-Wise programme may provide insights into the structure of a web-site for marine biotechnology, since it has case studies, technological information for companies, on-line partnering, a user club section, and other more general information.*

*The* ***NNFCC***[98]***,*** *which took over the activities of ACTIN and the Plant Protein Platform, was launched in November 2003. It is based in York and has the slogan 'From crops to cashflow: building sustainable supply chains.' Its core funding is provided by Defra. NNFCC will become the UK's main information point for industry and academia, and will also advise government on future directions in this area. It has a major technology translation role, funded by DTI under contract until 2007. It is a subscription organisation and will also carry out commercial contract work. ACTIN, founded in 1995, was funded by a consortium of industry (ICI, Zeneca, DuPont, Dalgety, British Sugar, Cargill Seeds, PBI-Cambridge and PIRA International), farmer groups (Home Grown Cereals Authority and National Farmers' Union), BBSRC and government (DTI, Defra – then MAFF). It supported and developed a strong network of interest in alternative uses and alternative crops and worked closely with LINK in a £4 million programme for new uses for plants.*[99] *The LINK programme, sponsored by BBSRC, Defra, EPSRC, DTI and SEERAD (Scottish Executive Environment & Rural Affairs Dept), funded 21 projects from 1996 to 2002. This programme was successful in encouraging SMEs to become involved.*

NERC also funds a great deal of infrastructure and capital support for marine sciences, including research vessels, costs of many of the relevant culture collections and facilities development projects.

#### *RCUK Follow-on Fund*

The first stage of this closed in early 2004. The BBSRC fund is likely to continue and is aimed at developing proof of concept and prototypes from BBSRC-funded new knowledge and embryo products.

---

97 see http://www.biowise.org.uk/

98 see http://www.nnfcc.co.uk

99 Competitive Industrial Materials from Non-Food Crops LINK programme – see http://www.ost.gov.uk/link/foocim.html

### *HEI programmes*

**SRIF** the Science Research Investment Fund and **HEIF** the Higher Education Innovation Fund are aimed at HEIs.

The **SRIF** (Science Research Investment Fund 2000-2002, Science Research Infrastructure Fund 2002-2004), jointly provided by HEFCE (Higher Education Funding Council of England) and the Wellcome Trust, is aimed at supporting capital infrastructure and facilities in which high quality research can be carried out, particularly in scientific areas of national strategic priority. The work within these is also intended to be collaborative, between HEIs, charitable bodies, NHS Trusts, Government and industry, and can encompass buildings, research equipment and support and communication networks. The first round was announced in 2000 and the second round closed in May 2003.

The **HEIF** (Higher Education Innovation Fund), a joint initiative between HEFCE and OST, has £186 million allocated for the period 2004-2006, and is aimed at individual or collaborating HEIs who wish to improve technology and knowledge transfer and the business awareness of their staff. The second round was announced in February 2004, resulting in 124 awards, including 22 ‘Centres for Knowledge Exchange Activities’. The decision has been made that this support will form a permanent ‘third stream of funding’ for HEIs, to stimulate and recognise the efforts at technology transfer that the usual assessment exercises ignore.

The HEIF absorbed the **University Challenge** and **Science Enterprise Challenge** activities from 2003 onwards. These achieved their first funding rounds in 1999 and second rounds in 2001. The University Challenge programme was the equivalent in England of the Proof of Concept Fund in Scotland. In the first round, £65 million was available, £20 million of this from HEI resources and other funds from the Wellcome Trust and Gatsby Charitable Foundation, for 28 HEIs and 9 PRSEs. The second round supported 17 institutions in 5 consortia with £21 million. In the Science Enterprise Challenge programme, 12 centres of excellence were established in the first round of £29 million, which attracted a further £28 million from external sources, and a further £15 was invested in 7 consortia in the second round.

The HEIF should be investigated as a source of funding for relevant marine biotechnology activity, especially as it includes HEIs, PSREs and the establishment of centres of excellence for proof of principle, knowledge transfer, and business development.

## *Programmes bringing HEIs and companies together*

Newer initiatives bringing academic research, applications and businesses together include **Knowledge Transfer Networks** and **Knowledge Transfer Partnerships**. For SMEs, a useful ‘front door’ for support programmes is the SBRI Programme.[100]

***Knowledge Transfer Networks (KTN) -*** These build on the Faraday Partnership experiences, and include a wider range of networking activities to enhance knowledge transfer from HEIs and PSREs into industry, targeting activities and sectors that can maximise productivity. They are targeted or thematic programmes and not responsive

[100] see http://www.sbri.org.uk/aboutus.asp

mode; thus if marine biotechnology is to be eligible, it is dependent on the relevant RC or government department opening a call for the area. Notwithstanding this, it may be possible to present a position paper arguing for establishment of a KTN in marine biotechnology and exploitation.

A similar programme in Scotland, which is intended to support research-industry interactions that are not otherwise being supported, is Scottish Expertise Knowledge and Innovation Transfer, SEEKIT. This involves research institutes and technology transfer offices as well as HEIs.

***Knowledge Transfer Partnerships (KTP) -*** These are direct collaborations between HEIs and specific companies, in which graduates and other recently qualified people undertake specialised knowledge transfer from the HEI to the company, building on the Teaching Company Scheme. A similar activity in Scotland, which involves R&D collaboration between HEIs and industry, is the SME Collaborative Research programme ScoRE.

## *Economic support programmes for companies*

The work undertaken as part of the Government's innovation funding review revealed that about 87% of SMEs are generally able to obtain the financing they need. The remaining 13% find varying difficulty but, since a high proportion of these are high-risk, special attention needs to be paid to these. Marine biotechnology start-ups and resource development companies would, by their nature, fall into this class.

***Regional Venture Capital Fund (RVCF) Programme -*** This group of 9 funds, RVCFs, was established in England in 2000 as a means of bridging early-stage equity gap and stimulating SMEs that demonstrate growth potential. Regional Fund Managers were chosen via open tender and work with the local RDA and the DTI's SBS (Small Business Service). The original plan was to source 50% of the funds from SBS plus European Investment Fund and 50% obtained from private sources by the Fund Managers. The eventual size at closing in 2003 was over £250 million, about 1/3 from public sources and 2/3 from private. The RVCFs vary in size from North East RVCF at £15 million to London RCVF at £50 million; most are in the £25-30 million range.

A Regional Venture Capital Fund can invest or co-invest up to a maximum of £250,000, following up with a further £250,000, whether or not there are other investors. Investment can be equity or debt and a wide range of companies can take part, exceptions being agricultural, horticultural, forestry and some other service companies. By November 2003, 70 companies had been supported; by April 2004 this had risen to 107 investments (including follow-ons) in 83 companies.[101]

Since marine biotechnology exploitation has not previously been classified as agriculture and algal farming is arguable, start-ups in England could be eligible for support, but this remains to be tested.

### *Grant for Investigating an Innovative Idea*

Within SMART, funding was available to SMEs for Technology Reviews and Technology Studies. These were formally closed in May 2003 and are now replaced by **Grants for Investigating Innovative Ideas**, aimed at SMEs for sums up to £500,000, and available

[101] Chapter 12 of the DTI's Departmental Report for 2004, see http://www.dti.gov.uk/expenditureplan/report2004/

within the overall Small Business Services package of the DTI.[102] This scheme was used by over 350 businesses between June 2003 and April 2004. It would seem suitable for marine biotechnology businesses trying to establish new products or processes, and perhaps also for bioreactor investigation.

Other programmes are available in general for small companies, including the Small Firms Loan Guarantee Scheme, the Early Growth Funding project, providing between £50,000 and £100,000, and, for businesses starting in deprived areas with local impact, the Bridges Community Development Venture Fund. There is also an increased emphasis on provision of business training for start-ups and small businesses. A local Enterprise Agency is best-placed to advise on these.

### *NESTA*

Although this programme is thought of as being more for the creative arts, NESTA is one of the instruments for support of innovative science and technology in design, manufacturing and start-up businesses. NESTA was established in 1998 with an endowment from the National Lottery of £200 million, extended in 2003 with a further £50 million. NESTA has so far invested £40 million in new activities and is concerned that the DTI's Innovation Report and the resulting National Technology Strategy completely omit the role of science and technology in the creative industries.[103] NESTA might be a route to funding of innovative PR and communications media for the marine bioscience and biotechnology sector.

**TABLE 25: EXAMPLES OF COSTS OF COMPONENTS OF A SUPPORT PROGRAMME**

| COMPONENT | EXEMPLAR | COMMENTS |
|---|---|---|
| Defining the sector, creating the message and engaging enthusiasm | Fore*sight* Marine Panel Marine Biotechnology Group | Little overall costs – relies on volunteer time of group; secretariat should be funded; expenses for volunteers and budget for communications are recommended. |
| Networking (Academic-Academic) | Yorkshire Tissue Engineering Group[104] | Regional collaboration between Universities of York, Leeds, Sheffield and Bradford – runs an EPSRC-funded regional network on Post-Genomic Tissue Engineering, £64,000 over 3.5 years. |
| Networking (Academic-Industry) | Faraday Partnerships<br><br>Knowledge Transfer Networks | >£2 million each, over 3-4 years, with expectation of securing further funding through 'commercial' activities (membership fees, meeting attendance fees, sponsorship, industry co-funding) as well as further public funding through project bids.<br>The National Composites Network gained £4.74 million fromDTI and £14 million from RDAs in the first KTN round (april 2004), with a target of an additional £11.25 million from participating industry. |
| Industry support network | MDIS | Medical Devices in Scotland – funded by Scottish Enterprise at £480,000 over 3 years, plus subscriptions, meeting and mission fees and other private funding. |

[102] see http://www.dti.gov.uk/innovative-idea/index.htm
[103] see http://www.nesta.org.uk/mediaroom/newsreleases/3904/
[104] see http://www.yteg.org.uk/

### TABLE 25: CONT

| COMPONENT | EXEMPLAR | COMMENTS |
|---|---|---|
| Thematic programmes | NERC Marine & Freshwater Microbial Biodiversity<br>NERC Environmental Genomics Programme | >£7 million for 5 years 2000-2005 (including some SBRI grants).<br>£16.5 million for 5 years 2000-2005; 4/28 current projects involve marine or aquatic genomes. |
| Case study programmes | Bio-WISE[105] | £3m provided for 21 case studies within a £13 million 4 years 1999-2003 programme, funded by DTI with European Regional Development Fund input. |
| Centres of Excellence | UK Centre for Tissue Engineering[106]<br>European Centre for Marine Biotechnology | >£9.7 million 2001-2007 – Universities of Liverpool and Manchester, funded by a 6-year Interdisciplinary Research Collaboration Award (BBSRC, EPSRC, MRC).<br>Approx. 2/3 of the total SAMS renovation and new buildings cost of £8.3 million. |
| Centres for Knowledge Transfer | BITE CIC[107]<br>ITI Scotland[108] | Centre for Industrial Collaboration formed by combining biomaterials/tissue engineering skills of Universities of York, Leeds, Sheffield, but geared to industry collaboration – funded by the RDA Yorkshire Forward as part of a £11 million programme (includes >5 other CICs in other technology-driven industrial sectors).<br>Intermediary Technology Institutes, virtual engines for transferring research knowledge and inventiveness into companies, to the tune of £450 million over 10 years (c. 1/3 for Life Sciences). |
| Communications programme | OST Science and Society Programme | £4.25 million 2005-2006, >£9 million 2006-2007 for projects that increase the public capacity to understand and appreciate science, and engage the public, science community and policy makers in dialogue. |
| Training | Knowledge Transfer Partnerships | Place graduates/PhDs in companies for technology/knowledge transfer to company, and acquisition of industrial knowledge/skills by graduate; company costs £14,000-£25,500 per placement, topped up by public funds |

[105] see http://www.biowise.org.uk/
[106] see www.ukcte.org
[107] see http://www.bitecic.com/
[108] see http://www.itilifesciences.com/

# ANNEX E: INDIVIDUALS CONTACTED FOR RESPONSES TO SWOT AND RECOMMENDATIONS

### TABLE 26: CONTACTS

| Research & Academics | |
|---|---|
| **Contact** | **HEI/Institute** |
| Dr Ivan Heaney | Department of Agriculture and Rural Development for Northern Ireland |
| Dr Frithjof Kuepper | CCAP, SAMS Dunstaffnage |
| Professor Graham Shimmield FIBiol | ECMB Dunstaffnage |
| Professor Brian Austin | Heriot Watt University |
| Dr J Grant Burgess | Heriot Watt University |
| Dr Michelle Tobin | Hull University |
| Professor Clive Page | King's College London |
| Dr Ian Joint | MBA Plymouth |
| Dr Willie Wilson | Plymouth Marine Laboratory |
| Professor Nick Christofi | Napier University |
| Dr Martin Embley | Natural History Museum |
| Dr Tony Clare | Newcastle University |
| Dr David Robins | Plymouth Marine Laboratory |
| Professor John W Lewis | Royal Holloway, University of London |
| Professor M. C. Thorndyke | Royal Holloway, University of London |
| Professor A F Rowley | University of Wales, Swansea |
| Professor Marcel Jaspars | University of Aberdeen |
| Professor Monty Priede | University of Aberdeen |
| Professor J. A. Callow | University of Birmingham |
| Professor Len V Evans | University of Buckingham |
| Professor John Parkes | University of Cardiff |
| Dr Sarah Cornell | University of East Anglia |
| Dr Gill Malin | University of East Anglia |
| Dr Phillip Williamson | University of East Anglia |
| Dr Kate Darling | University of Edinburgh |
| Professor David Nedwell | University of Essex |
| Dr Mark Osborn | University of Essex |

| Research & Academics | |
|---|---|
| **Contact** | **HEI/Institute** |
| Dr Tony Clare | University of Newcastle upon Tyne |
| Dr Ian Head | University of Newcastle upon Tyne |
| Dr Jeremy Thomason | University of Newcastle upon Tyne |
| Dr Alan Ward | University of Newcastle upon Tyne |
| Professor Paul Williams | University of Nottingham |
| Dr Peter Holland | University of Oxford |
| Dr Iwona Beech | University of Portsmouth |
| Mr Graham Bremer | University of Portsmouth |
| Dr Colin Waring | University of Portsmouth |
| Dr Keith Haines | University of Reading |
| Professor Phillip Wright | University of Sheffield |
| Dr Ralf Prien | University of Southampton |
| Dr Mark Varney | University of Southampton |
| Dr Chris Todd | University of St Andrews |
| Dr M Wyman | University of Stirling |
| Professor Jim Lynch | University of Surrey |
| Dr Derek Jackson | University of Ulster |
| Dr Aileen Moore | University of Ulster |
| Professor Michael Young | University of Wales, Aberystwyth |
| Dr Jonathan King | University of Wales, Bangor |
| Professor Nick Mann | University of Warwick |
| Dr Alan J Blakey | Actinomed |
| Dr Andrew Mearns Spragg | Aquapharm Bio-Discovery Ltd |
| Steve Rumford | AstraZeneca |
| Dr Barbara Blaney | BIA Scotland |

### Table 26: Cont

| Research & Academics | |
|---|---|
| **Contact** | **HEI/Institute** |
| Professor Kenneth Timmis | University of Essex |
| Professor Mike Cowling | University of Glasgow |
| Dr Rupert Ormond | University of Glasgow |
| Professor Alan Bull | University of Kent |
| Professor Don Ritchie | University of Liverpool |
| Dr Mark Trimmer | University of London Queen Mary |
| Dr Pauline Handley | University of Manchester |

| Commercial | |
|---|---|
| **Contact** | **Company** |
| Ian Scade | Carapacics Ltd |
| Robin Teverson | Finance Cornwall |
| Dr Dave Woodwark | FIRST Faraday Partnership |
| Michelle Scott | Glaxo Smith Kline |
| Dr Charles Bavington | Integrin Advanced Biosystems |
| Alasdair Munro | Top Country Development |

# ANNEX F: REFERENCES & WEBSITES


| |
|---|
| A New Analysis of Marine-Related Activities in the UK Economy with Supporting Science and Technology August 2002, David Pugh & Leonard Skinner for IACMST |
| *A Practical Guide to Cluster Development: A Report to the Department of Trade and Industry and the English RDAs* December 2003 Ecotec Research & Consulting for DTI |
| *Advanced Polymers for Medical Applications* Kalorama Information KLI 513 899 2002, ISBN 1-56241-781-9 |
| *Angiogenesis Inhibitors & Stimulators* Theta Publications, PJB Publications 2002 |
| *Antidepressants world prescription drug markets*, Theta Report #1234 December 2003, PJB Publications |
| *Apoptosis: New Growth Opportunities*, Business Communications Co Inc July 2000 |
| *Assessment of Marine Science activities and Capability in Scotland (Abridged Version)* October 2001, Scientific Generics Ltd for Highlands & Islands Enterprise and Scottish Enterprise |
| Baran Et, Tuzlakoglu K et al., Multichannel mould processing of 3D structures from microporous coralline hydroxyapatite granules … J Mater. Sci.: Mater. Med. 15 (2004) 161-165 |
| *Biomaterials from Marine Sources*, Business Communications Company Inc Report No. RC-184R, February 2003 |
| *Biomaterials from Marine Sources*, Business Communications Company Inc Report No. RC-184R, February 2003 |
| *Biomaterials Strategy for Scotland*, BioBridge 2003 for SE Edinburgh & Lothian |
| *Biotech Research Reagents*, May 1998. Theta Publications, PJB Publishing Ltd) |
| *Blaue Biotechnologie: Stand und Perspektiven der marinen Naturstoffe*, Technologiestiftung Schleswig-Holstein, June 2003 pp 25-26 |
| Bridging the finance gap: a consultation on improving access to growth capital for small businesses April 2003, HM Treasury and DTI's Small Business Service |
| Business Clusters in the UK – A First Assessment February 2001,Trends Business Research, |
| *Competing in the global economy: the innovation challenge* December 2003 The UK DTI, Chapter 6 |
| *Competitiveness: cluster-based policies* 2002 The Cluster Competitiveness Group SA, Cerdanolya, Barcelona Spain |
| *Diet and Fat-free foods market assessment 2001*, ed. S Taylor, Key Note (2001), ISBN 1-86111-379-9 |
| *Drug Delivery Systems, Freedonia Reports 2001* |
| Enhancing the Productivity of the British Economy: Cluster lessons and others September 2001 Paul Miller Trends Business Research |
| *Europe Nutraceuticals*, Datamonitor 2002 |
| *European Strategy on Marine Research Infrastructures* 2003, the Academy of Finland, for the European Strategy Forum on Research Infrastructure, Publications of the Academy of Finland 6/03 |
| Feasibility Study for the development of a marine science and technology (MST) cluster in Plymouth Final Report April 2003, GHK & BMT, for the City of Plymouth |
| *Global Nutraceuticals*, Datamonitor August 2003, Report No 0199-0759 |
| Harvey A., *Drug Discovery Today*, Vol 5 No 7 July 2000 |
| *Integrating Marine Science in Europe* ESF Marine Board Position Paper 5, November 2002 |
| Investing in Innovation. A Strategy for science, engineering and technology July 2002, DTI, HM Treasury and DfES (Dept for Education and Science) |
| Kelly D P ,in Medical Device Manufacturing and Technology, World Market Research Centre September 2000 p40 |
| Marine Foresight Panel Ireland 2003 |
| Marine Science Review, Report of Visit to Maryland & Virginia, New Park Management June 2001, chapter 4 |
| *Neuropathic Pain*, EP Publications, WWMR Inc, www.WWMR.com |
| *New Development in Biomaterials*, a Clinica report, PJB Publications 2000 |

| |
|---|
| New Trends in Viral Diagnostics, Clinica, 2001 |
| Surviving Uncertainty: The Pan European Mediscience Review 2002, Deloitte & Touche 2002 |
| *The Global Crop Protection Industry in 2010*, Agrow Reports DS221, PJB Publications 2001 |
| The Hellenic Centre for Investment, www.elke.gr |
| The International Regime for Bioprospecting, Existing Policies and Emerging Issues for Antarctica UNU/IAS Report August 2003 |
| *The UK Industry Food Market Review*, ed. D Fenn, Key Note Ltd (2002), ISBN 1-84168-394-9 |
| *UK Marine Industries World Export Market Potential*, D Westwood for the Fore*sight* Marine Panel 2000, ISBN 1-902536-38-X |
| Marine Biotechnology, a European strategy for marine biotechnology ESF Marine Board Position Paper 4, December 2001 |
| *Marine Science in Scotland. A strategy for developing its potential* October 2004, for Highlands & Islands Enterprise and Scottish Enterprise, including Report by Professor I N McCave |
| *Marine Technology, report of the eighth Foresight Seminar, 13 May 1999*, with reference to the Department of Defense's Office of Naval; Research, http://www.ma.hw.ac.uk/RSE/govt_responses/commercialisation/seminar_reports/foresight/f08may99.pdf |
| *Prospecting Bioscience for the future of non-food uses of crops* January 2004 A McMeekin, M Harvey *et al.* for the Government Industry Forum on Non Food Uses of Crops |
| *Science & innovation investment framework* 2004-2014 July 2004 HM Treasury, DTI, DfES, page 8 |
| UK Biotechnology Industry. Government response to the House of Commons Trade and Industry Committee's twelfth report of the session 2002-03 Appendix to Sixth Special report of Session 2002-03, November 2003, The Stationery Office Limited, London |
| *UK Marine Industries World Export Market Potential* October 2000, Douglas-Westwood Associates for the Fore*sight* Marine Panel |

| |
|---|
| http://www.abpi.org.uk/statistics |
| http://www.biohydrogen.nl |
| http://www.biomarket.rothamsted.ac.uk/index.php |
| http://www.biowise.org.uk/ |
| http://www.bitecic.com/ |
| http://www.diversa.com/markprod/mark/induappl.asp |
| http://www.dti.gov.uk/expenditureplan/report2004/ |
| http://www.dti.gov.uk/innovative-idea/index.htm |
| http://www.dti.gov.uk/technologyprogramme |
| http://www.floridabiotech.org/ |
| http://www.i10.org.uk |
| http://www.ideas21.co.uk/317 |
| http://www.itilifesciences.com/ |
| http://www.innovation.gov.uk |
| http://www.nerc.ac.uk/funding/thematics/envgen/ |

| |
|---|
| http://www.nerc.ac.uk/funding/thematics/mfmb/ |
| http://www.nesta.org.uk/mediaroom/newsreleases/3904/ |
| http://www.novamatrix.biz |
| http://www.ost.gov.uk/link/foocim.html |
| http://www.quorex.com |
| http://www.sbri.org.uk |
| http://www.sbri.org.uk/aboutus.asp |
| http://www.sbs.gov.uk/default.php?page=/financegap/default.php |
| http://www.scotland.gov.uk/news/2000/10/se2767.asp |
| http://www.scottish-biomedical.com, , |
| http://www.theratase.com web-site |
| http://www.ukcte.org |
| http://www.whitehouse.gov/bioshield/ |
| http://www.yteg.org.uk/ |