Capabilities and Opportunities for Joint Working on Biorefining and Industrial Biotechnology

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A Project for Innovation Norway and Technology Strategy Board.

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The NNFCC

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Contents

Figures

Tables

Executive Summary

Innovation Norway and the UK's Technology Strategy Board have signed a Memorandum of Understanding (MoU) with the intention of developing a partnership in the areas of industrial biotechnology and biorefining. Both countries have expertise and activities in biorefining and biotechnology and there are already extensive collaborations between the countries on which this partnership can be built. This report fulfils the first action under the MoU in identifying high level opportunities and synergies for Norway and the UK.

An assessment of the market pull for different products, the availability of raw materials, expertise and infrastructure in the UK and Norway resulted in the identification of a number of areas where the countries have mutual or synergistic interests and expertise. These areas were consolidated and refined into a series of key short term and longer term opportunities for collaboration between the countries.

The short term opportunities are:

1. Using microalgae for omega oils for the aquaculture industry and for bioactive ingredients for the consumer goods industries.
2. Using marine wastes as a source of bioactive molecules for the consumer goods industry.
3. Using wood as a feedstock for the production of bulk chemicals and fuels.

In the longer term, a number of joint projects could be envisaged. These include:

1. The utilisation of lignin from the pulping industry as a feedstock for high value chemicals production.
2. The production of chemicals and fuels from macroalgae.

These opportunities are the starting point for a more detailed investigation of innovation needs and the underpinning research required to realise these opportunities. A series of workshops and exchange visits will be required to build relationships and to develop detailed proposals for research and development projects. The approach needed in these meetings will differ depending upon the target end market.

Recommendation 1 - Developing Collaborative Ventures between the UK and Norway in Areas where there are Synergistic Interests and Capabilities. The approach needed to bring together stakeholders from the UK and Norway will differ depending upon the end market targeted.

The speciality chemical using industries are secretive about products in development and prefer to discuss what functionalities are desirable for their product ranges. As a result, we suggest that any meetings should initially focus on the specific competences offered by specific institutes and companies. This will aid the speciality chemicals industry to identify to what extent each of the interested parties could help in the development of specific bioactives of interest and will help more focussed, potentially confidential discussions on opportunities, probably under non disclosure agreements. The Chemistry Innovation KTN is the key contact point in the UK to develop contacts and relationships in the speciality chemicals sector.

In contrast, the chemicals required by the bulk chemicals industry is a better defined area, with specific chemicals of interest for the UK bulk chemicals industry including ethanol, bio-butanol, MMA, lactic acid and succinic acid. In this sector, it is important to first establish that the technology developers have a strategic interest in developing a technology for a particular feedstock. Chemistry Innovation KTN can provide the key contacts with industrial end users in this sector, while Biosciences KTN is the key contact for the industrial biotechnology industry. The newly formed UK Algal Bioenergy Special Interest Group provides a key link with the UK macroalgae and microalgae industries.

Recommendation 2 – There is a need to stimulate relationships between complementary enterprises in both countries**.** This could be achieved through exchange of personnel and the joint management of specific projects. Exchange of academic personnel could be funded through existing research council schemes, but there needs to be further considerations on how the exchange of industrial personnel could be facilitated and funded.

Collaboration should be facilitated between centres with expertise in:

1. Fermentation.
2. Macroalgae cultivation.
3. Marine biobanks.
4. Biocatalysis.

In addition to these more focussed actions, a number of overarching actions will need to be developed to help promote the development of joint UK-Norway projects and collaborations. The following recommendations provide a basis for developing these actions.

Recommendation 3- Mechanisms for the identification of stakeholders in both the UK and Norway need to be developed and publicised more widely. While both Innovation Norway and Technology Strategy Board have made progress in developing tools to promote stakeholder identification and networking, these tools need to be advertised widely in both countries to ensure the full value of these resources is maximised.

Recommendation 4 – Consideration needs to be given on how to engage with industrial stakeholders. In particular, it may be difficult to get industrial stakeholders to engage with other stakeholders without prior information exchange on the benefits of any potential collaboration e.g. upfront information on funding could help stimulate industrial engagement.

Recommendation 5 - Upcoming calls in the European Framework Programme and similar schemes such as Interreg should be reviewed. We suggest that Innovation Norway and Technology Strategy Board focus networking and consortia building activities around these calls as this could be one mechanism of funding collaborative activities.

Recommendation 6 - The TSB and Innovation Norway should review their countries participation in ERA-Nets aligned to Industrial Biotechnology and Biorefining.   The ERA-Net programme could provide an effective mechanism for funding collaborative research projects involving UK and Norwegian partners.

Recommendation 7 – There is a need to promote TSB and Innovation Norway funding schemes such as the Norwegian IFU contract scheme which could provide a mechanism for funding bilateral projects. It may be pertinent for TSB to consider, especially for the high value chemical opportunities, developing a call similar to the ‘High Value Chemicals from Biomass’ call, with a scope focusing on the identified opportunity areas but not excluding other opportunities. We estimate that for each of the four opportunities identified in this report, around £2 million public funding would be required to support four to five projects based on 50% public funding being matched with 50% industrial funding.

In conclusion, both the UK and Norway have expertise in both biorefining and industrial biotechnology. There are areas where both the UK and Norway have strength, while in other areas; one country may have a particular strength. While there are already links between the UK and Norway in a number of relevant areas, such links have developed spontaneously rather than through any concerted action. The development of the MoU between the UK and Norway in this area can help promote opportunities in both countries which otherwise may not have developed and thus create important new opportunities for both countries.

1 Background

On the 23rd February 2011, Innovation Norway and the UK's Technology Strategy Board (TSB) signed a Memorandum of Understanding (MoU) with the intention of developing a partnership in the areas of industrial biotechnology and bio-refining. The aim of the partnership is to maximise the exploitation of research and development between the two countries.

The agreement follows the bilateral and global partnership signed on 19 January 2011 by UK Prime Minister David Cameron and Prime Minister Stoltenberg of Norway, which included an agreement to strengthen our trade and investment relationship in a number of areas, including biotechnology.

Both the TSB and Innovation Norway believe that industrial biotechnology and biorefining underpin the bio economy, which in Europe has a market size of €2 trillion and employs 21.5 million people. Investment in these technologies can help to meet the increasing demand for a *sustainable* supply of food, industrial products and fuels.

Bilateral cooperation between the two countries can help build knowledge exchange, build partnerships for mutual benefit, and provide the impetus for longer lasting collaboration in areas identified as being strategically important. Both Norway and the UK have expertise and activities in biorefining and biotechnology on which the partnership can be built.

The first action under the MoU was to identify high level opportunities and synergies for Norway and the UK. To complete this action the NNFCC have been engaged to perform and report on a preliminary scoping study to identify key areas for collaboration.

2 Introduction

Biorefining is a broad term for the sustainable processing of biomass resulting in the generation of multiple products ranging from feed, fuels, and chemicals to energy and heat. A biorefinery can be a concept, a facility, a process, a plant, or even a cluster of facilities[1]. Industrial biotechnology, as shown in Figure 1, is one of a suite of technologies underpinning the development of biorefineries. Industrial biotechnology can be defined as the application of science and technology to living organisms, as well as the parts, products, and models thereof, to alter living or non-living materials for the production of knowledge, goods and services[2].

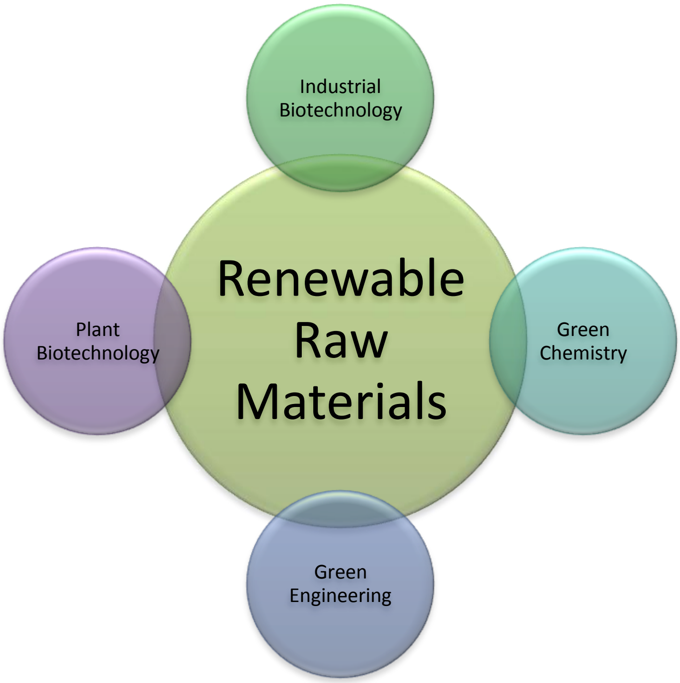

Figure 1 - Conceptual Diagram of Biorefining and Underpinning Technologies.

Both the UK and Norway have activity in biorefining and industrial biotechnology. Norway has a particular strength in forest based, marine and thermochemical biorefineries, while the UK has a greater focus on the development of crop based and thermochemical biorefineries. Both countries have identified industrial biotechnology and biorefining as key technologies for future economic growth.

In the UK, the Government invited an industry-led Industrial Biotechnology Innovation and Growth Team (IB-IGT), to set out its vision for IB by 2025 and actions were recommended to Government in 2009[3]. In its response to the report the Government recognised that IB can contribute to sustainable, low-carbon growth in the UK and beyond through the development of new and less carbon intensive products and processes[4]. The UK Government placed IB at the heart of its drive

[1] IEA Task 42 on Biorefineries

[2] OECD Definition

[3] Maximising UK Opportunities from Industrial Biotechnology in a Low Carbon Economy. May 2009 http://www.berr.gov.uk/files/file51144.pdf

[4] Government Response to the Industrial Biotechnology Innovation and Growth Team Report to Government. June 2009. http://www.berr.gov.uk/files/file51891.pdf

towards a greener future and greener jobs; stating its wider adoption will equip companies to take advantage of new and emerging as well as established markets[5]. Following the recommendation of the IB-IGT, the UK has made significant investments in its industrial biotechnology capabilities including the construction of an open access industrial biotechnology demonstration facility at the Centre for Process Innovation[6]. More recently, the UK Coalition Government has set ambitious targets for the development of energy from waste through anaerobic digestion in the UK[7].

Norway has also recognised the potential of industrial biotechnology to act as an economic driver for the future. Norway has recently developed its medical and marine biotechnology industries and has an established and world leading forest industry. This industrial background coupled with Norway's ability to make significant strategic investments could lead to a rapid development of its industrial biotechnology capabilities.

Bilateral cooperation between the two countries can help build knowledge exchange, build partnerships for mutual benefit, and provide the impetus for longer lasting collaboration in areas identified as being strategically important. Bilateral collaboration in the area of biorefining will be beneficial when:

A partner provides:

- Access to sustainable sourced renewable raw materials
- Underpinning research expertise and facilities
- Knowledge or facilities for process or product development
- Access to a market for technology, process or product
- An industrial community with the ability commercialise products

Or where partners:

- Have a common source of sustainable renewable raw materials
- Have a common policy or market need
- Can operate synergistically on fundamental research areas
- Can operate synergistically on development projects
- Enhance process or product development through facilities sharing
- Can provide complimentary opportunities for market development

There is already extensive collaboration between the UK and Norway within both biorefining and industrial biotechnology; this provides a precedent and a firm basis by which to improve and build further linkages. Existing projects cover a range of disciplines relevant to industrial biotechnology and biorefining and include:

- BioAlgaeSorb is a 3.96 million euro (£3.53 million) FP7 project bringing together Norsk Bioenergiforening NoBio, University of Durham, University of Swansea, Varicon Aqua

5 Government Response to the Industrial Biotechnology Innovation and Growth Team Report to Government. June 2009. http://www.berr.gov.uk/files/file51891.pdf
6 From Innovation to Commercialisation in Industrial Biotechnology. CPI.
7 http://www.decc.gov.uk/en/content/cms/news/pn10_77/pn10_77.aspx

Solutions. This project is looking at the potential for algae to be used in water bioremediation and CO_2 capture[8].

- The Bio-oil refinery project is a £1.4 million project brings together Norske Skogindusrier, Statoil Petroleum, Holmen Energi, Sodra Cell and Fibortangen Vekst og ut vikling. R&D partners in the project are PFI, Aston University and NTNU. This project is investigating the potential for the production of fast pyrolysis oil from Scandinavian Forest Residues[9].
- Glycomar have a nutritional technology licensing and collaboration agreement with Scanbio, worth up to £4 million a year in gross sales[10]
- The HotZyme project is a 7.74 million euro (£6.93 million) FP7 project includes University of Exeter and Stiftelsen Norges Geotekniske Institutt in Norway. It aims to identify thermostable hydrolases from hot terrestrial environments[11].
- The British Bioalcohols Group have an existing relationship with the University of Norway (steam explosion of biomass), and are developing projects with CAMBI and Agroplas[12].
- Professor Marcel Jaspers (University of Aberdeen Marine Biodiscovery Centre) is a visiting professor at MabCent, University of Tromso, Norway[13].

This project has investigated the strategic benefits to the UK and Norway for collaborating in the areas of industrial biotechnology and biorefining. It identifies the key opportunities where bilateral cooperation would be beneficial and is based on an assessment of resources, raw materials, expertise, supply chains and market pull for specific products.

This study has taken a macro level view of the potential for collaboration between the UK and Norway. Therefore, while a range of potential stakeholders in each of the collaboration areas has been identified in this report, it should be noted that this is in no way an exhaustive list and that additional stakeholders will exist in both countries.

[8] http://www.bioalgaesorb.com/
[9] http://www.pfi.no/PFI_Templates/Page____394.aspx
[10] http://www.glycomar.com/documents/Pressrelease07APR11.pdf
[11] Personal Communication with Jenny Littlechild, Exeter University 5th May 2011.
[12] Personal Communication from Keith Waldron, Institute of Food Research, Norwich, UK. 8th April 2011.
[13] Personal Communication with Marcel Jaspers, University of Aberdeen, UK.

3 Identifying Potential Collaboration Opportunities between the UK and Norway

An initial review of activity in biorefining and industrial biotechnology in the UK and Norway was performed. The following areas were considered;

- Market pull for suggested products
- Availability of resource, raw material, knowledge, infrastructure, supply chain.
- Identification of stakeholders in both countries

A number of areas were identified where both UK and Norway have mutual interest and expertise. It was identified that the UK and Norway both have expertise in micro and macroalgae technologies. Similarly, both countries have extensive coastlines providing a large potential area for macroalgae exploitation and both countries have waste CO_2 and heat streams. We suggested the UK and Norway could work on the development of algal technologies such as those to exploit waste heat and CO_2, and to produce macroalgae for fuels and energy. There is also the potential for joint collaboration in the development of anaerobic digestion systems for high moisture content dairy and marine by products.

Synergistic relationships between the UK and Norway could be envisaged in other areas. Norway has an extensive and well established forestry industry. It was suggested that the UK could provide expertise in industrial biotechnology, thermal conversion technologies and green chemistry to add value to these resources, allowing the Norwegian forestry industry to become an exporter of bio-based chemicals to the UK or the world. The marine bio prospecting industry in Norway is world leading and could underpin the development of new enzymes for UK biotechnology companies and provide a source of novel bioactive components for the UK's innovative personal care sector. Finally it was noted that the UK and Norway both have extensive sea fish processing sectors which generate large amounts of by products. It was suggested that UK industrial biotechnology companies could provide technologies for adding value to these by products.

Based on this review a series of ten hypotheses were presented in an interim working document. The ten hypotheses are summarised in Appendix 2. The working document was used as a basis for further discussions with stakeholders. Based on these discussions the ten hypotheses were refined to four opportunity areas.

1. Using microalgae for the production of omega oils for the aquaculture industry and as a source of bioactives for consumer goods industry
2. Using macroalgae for chemicals and fuels
3. Using forestry products for chemicals and fuels
4. Processing marine wastes to bioactives for the consumer goods industry.

These four opportunity areas are summarised in Figure 2. The rationale behind the development of these hypotheses, the key stakeholder groups which should be involved, and information on key competences in these focus areas are explained in Section 4.

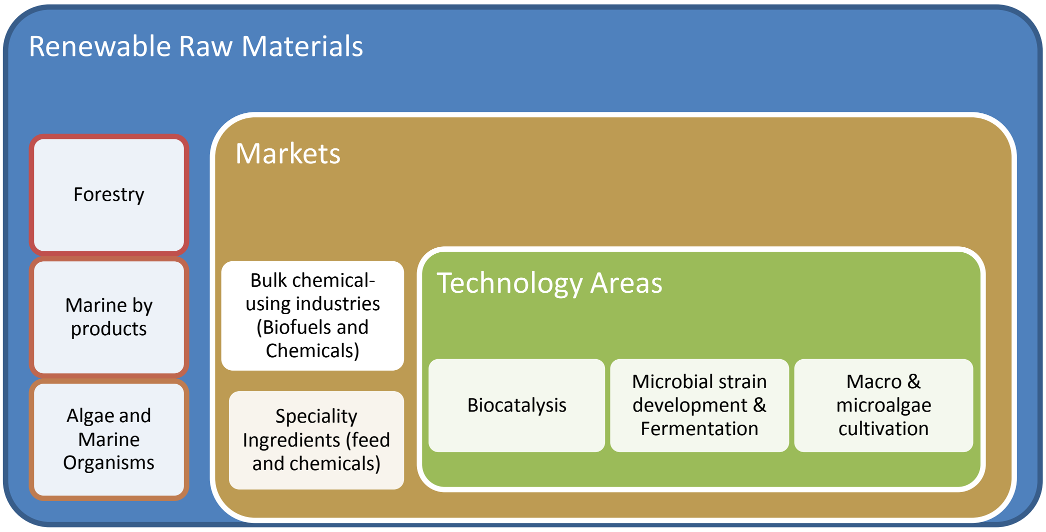

Figure 2 - Schematic of Potential Areas for Collaboration between UK and Norway

4 Specific Collaboration Opportunities

4.1 Opportunity 1 - Microalgal Products

4.1.1 Background

Microalgae (phytoplankton) can be grown in either marine or aquatic environments, in either land based ponds, reactors or in the sea, and as they do not utilise arable land, they avoid the contentious issue of land use change. Microalgae can be cultivated to produce a wide range of economically interesting metabolites ranging from anti-oxidants and flavour ingredients for cosmetics, personal care and food ingredient markets to polyunsaturated fatty acids such as the omega oils, DHA and EPA which can be used in nutraceuticals and for aquaculture. In 2008, the omega oils industry globally was worth $1,286 million, with around $323 million of this in Europe, (equivalent to 14,000 tonnes[14]). The market for speciality ingredients varies depending upon product. In 2010 the beta carotene market was worth $392 million[15], in 2006, the lutein market was worth $105.1 million[16], and in 2007, the astaxanthin market was worth $234 million[17]. Many of these products can be derived from synthetic or non-algal sources, but algal derived products may carry a premium over synthetic derived alternatives, especially where there are tangible performance benefits (e.g., beta carotene). The scale of production in both Norway and the UK is currently at a small scale and not likely to exceed 50 tonnes per annum[18] in either country.

While there is currently much hype about the potential for using microalgae as a feedstock for biodiesel production, there is also an increasing awareness of the potential for using microalgae as a source of speciality ingredients for feed, cosmeceuticals and nutraceuticals applications. The UK's consumer goods industry is constantly seeking new ingredients to provide product differentiation, and microalgae could provide novel compounds for this industry. Similarly, microalgae could be used in the UK and Norway's salmon farming industry as a sustainable source of omega 3 rich oils. The farmed salmon industry in both Norway and the UK is currently booming. Norway is currently the world's largest producer of farmed salmon, and the UK is the world's second largest producer[19]. Increasing the amount of omega oils in farmed salmon requires an increase in the amount of omega oils in feed, and microalgae are perceived to be one route to achieving this.

4.1.2 Hypothesis

The UK and Norway could work together to develop a microalgae to speciality ingredients and feed industry, drawing upon the bio banks and researchers in both Norway and the UK for strain development. The algal products could be used in the UK's consumer goods market, or in the farmed salmon industry in both the UK and Norway.

[14] Frost and Sullivan and the Global Organisation for EPA and DHA Omega-3. Global Overview of Marine and Algal Oil Ingredients Markets. 3rd September 2009.

[15] Industry Source and BCC 'The Global Markets for Carotenoids' March 2008.

[16] Frost and Sullivan (2007) Strategic Analysis of the Global Markets for Lutein in Human Nutrition.

[17] Industry Source.

[18] Dry weight

[19] Kenny Black, Scottish Association for Marine Sciences (2011), Personal Communication with Claire Smith 24th May 2011.

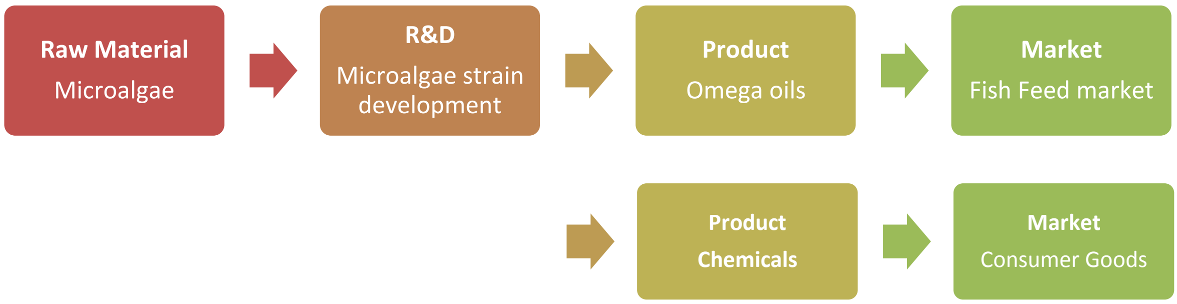

Figure 3 - Production of Microalgae for High Value Markets and Biofuels.

4.1.3 Current Activity

The UK has a number of projects investigating the potential for using microalgae as a source of ingredients for the consumer goods industry or farmed fish industry. These include work on identifying and growing bioactive microalgae compounds activity for inclusion in a range of health and beauty products and utilising the residues as a feed for farmed fish in a number of projects funded through the Technology Strategy Board and Renewable Materials LINK schemes[20]. The Research Council of Norway has funded a number of projects investigating the potential for using microalgae as a source of omega fatty acids for aquaculture feeds.

The UK and Norway are both involved in an FP7 project 'Bioalgaesorb' which is investigating the potential for microalgae in bioremediation and utilising the algae for a range of high value markets[21].

4.1.4 Principal Stakeholders

The development of this collaboration will require the input of four major groups of stakeholders, namely, UK and Norwegian research centres, the Norwegian and UK bio banks, UK chemical using industries and/or the UK and Norwegian salmon farming industry as shown in Figure 4 below.

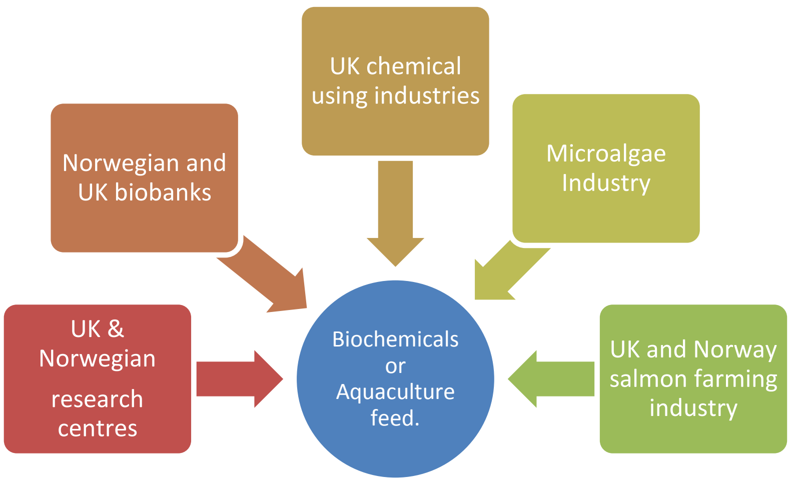

Figure 4 - Major Players in the Development of a Microalgae to Products Market

[20] http://www.pml-applications.co.uk/projects/health__beauty.aspx
[21] http://www.bioalgaesorb.com/

Table 1 below indicates the industrial and research capability to exploit the use of microalgae for omega oils and high value speciality chemicals. This capability analysis is based on the relative competence of each country and number of stakeholders in each area. The top of each box indicates a competency rating, based on the broad competency of both industry and academic stakeholders in the UK and Norway in each of the underpinning skill areas needed in this collaboration area. At the bottom of the box, we have also given an indicative figure for the number of industrial in this collaboration area, by activity area. We have broadly grouped the number of stakeholders in each area into three main groupings, namely, less than ten stakeholders, more than 10 stakeholders and more than 100 stakeholders.

Table 1 - Relative Strengths of the UK and Norway and Number of Potential Stakeholders Underpinning the Production of Microalgae for Speciality Chemical Applications and Aquaculture

Activity	Industrial Competence		Research Competence	
	UK	Norway	UK	Norway
Speciality Chemicals	Strong (>100)	Low	Strong	Medium
Aquaculture	Strong (>10)	Strong (>10)	Strong	Strong
Microalgae Production	Strong (>10)	Low (<10)	Strong	Medium
Biobanks	Medium (<10)	Low (<10)	Medium	Strong

The key players within each of these sectors and the key skill sets which could be used in the development of this opportunity are explained further in Section 5.

4.2 Opportunity 2 – Macroalgae for Chemicals and Fuels

4.2.1 Background

Macroalgae (seaweeds) are grown in marine or aquatic environments. Globally, over 12 million tonnes of macroalgae are harvested each year, mainly from cultivated stocks in Asia. Macroalgae have a wide range of existing applications including use in food, fertiliser, chemicals and cosmetic ingredients and the global macroalgae market is estimated at $6 million[22]. Both Norway and the UK have extensive coastlines which have extensive standing stocks of algae and have the potential for macroalgae farming. Both countries have traditionally supported an algal processing industry. Norway is the largest algae producer in Europe, harvesting around 130-180,000 tonnes of wild seaweed stocks each year[23]. Activity in Scotland is substantially lower, with less than 25,000 tonnes harvested mainly for liquid fertilisers and livestock feed markets.

Some macroalgae contain high levels of fermentable carbohydrates. Carbohydrate fermentation has the potential to produce a range of different chemicals, many of which have established fuel and chemical markets. These include ethanol, succinic acid, lactic acid, butanol and 1, 3 propandiol. In 2010, the global market size for ethanol was around 61 million tonnes, with a market value of around $1,000 per tonne gave a total market size of $61 billion dollars[24]. In contrast, lactic acid had a market size of just over 300,000 tonnes in 2010, and with a product price of between $1,300 to $1,600 per tonne gave a total market size of $390 to $480 million[25] while in 2011, succinic acid had a market size of 30,000 tonnes, and with a market price of between 2,000 to 3,000 tonnes had global market value of $60 to 90 million[26]. Succinic Acid in particular, is a rapidly growing opportunity. As macroalgae do not utilise arable land, and grow in saline water, there is no competition with terrestrial food crops and this makes them an attractive feedstocks for both biofuels and chemicals production. Seaweed carbohydrates are different to those found in terrestrial species. This necessitates the development of organisms which can ferment these sugars to chemical and fuels.

4.2.2 Hypothesis

The UK and Norway could work together to develop a macroalgae to chemicals industry, drawing upon Norwegian strengths in macroalgae production and the UK industrial biotechnology base for the benefit of the UK bulk chemical industry.

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[22] James, MA (2010) A review of initiatives and related R&D being undertaken in the UK and Internationally regarding the use of macroalgae as a basis for biofuel production and other non-food uses relevant to Scotland. Report commissioned by Marine Scotland. 79pp.

[23] James, MA (2010) A review of initiatives and related R&D being undertaken in the UK and Internationally regarding the use of macroalgae as a basis for biofuel production and other non-food uses relevant to Scotland. Report commissioned by Marine Scotland. 79pp.

[24] NNFCC (2010) Renewable Chemical Factsheet – Ethanol http://www.nnfcc.co.uk/publications/nnfcc-renewable-chemicals-factsheet-ethanol

[25] NNFCC (2010) Renewable Chemical Factsheet – Lactic Acid. http://www.nnfcc.co.uk/publications/nnfcc-renewable-chemicals-factsheet-lactic-acid

[26] NNFCC (2010) Renewable Chemical Factsheet – Succinic Acid. http://www.nnfcc.co.uk/publications/nnfcc-renewable-chemicals-factsheet-succinic-acid/at_download/file

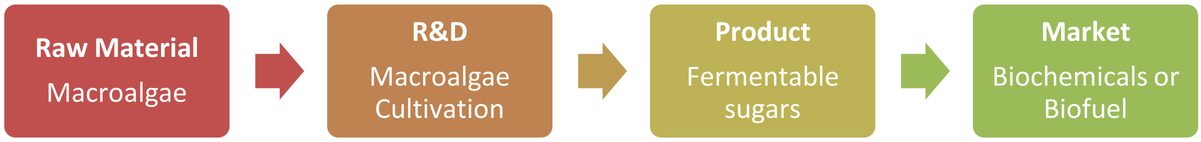

Figure 5 - Production of Macroalgae for Biochemicals and Biofuels

4.2.3 Current Activity

Norway is an international leader in the development of macroalgae as a feedstock for biofuels and biobased chemicals. There are several research projects, which are either in progress or have recently finished, aiming to commercialise the use of macroalgae for energy and biofuel purposes. Norwegian projects have investigated the cultivation of macroalgae both in conjunction with aquaculture enterprises for bioremediation and as a biofuel feedstock, particularly for bioethanol production. The Ocean Biopower 'Farming Seaweeds for Energy' project which ran from 2008-2010 investigated the optimal locations and economics of seaweed cultivation for biofuels. The MacroBiomass (2010-2012) is a project, funded by the Research Council of Norway, which is investigating the optimal technology for the large scale cultivation of macroalgal biomass. It consists of three strands, 1) optimising species and production of seaweed 2) determining how seasonal variations in seaweed quality affect bioethanol yield, and 3) identifying harvesting strategies to optimise fermentable sugar composition and the use of macroalgae for ethanol production.

Norwegian research on seaweeds for energy is largely focussed upon the use of seaweeds for bioethanol production. The Ocean Biopower 'Biofuels from Farmed Seaweeds' project investigated the fermentation of alginate to ethanol and the economics of using seaweed for different products, while Statoil have funded BioArchitecture lab in a €2-3 M project running from 2008 to 2011, to fund demonstrations of their technology for producing ethanol in Norway with a view to rolling this out throughout Europe. The 'From Biomass to Biogas – an Integrated Approach Towards Sustainable Recovery of Energy and Nutrients Project' (2009-2012) is a Research Council Norway funded project which is investigating different seaweed pre-treatment technologies, investigating technologies for using the sugar stream for bioethanol production and the production of biogas from the residual biomass.

While there is some practical research on macroalgae cultivation in the UK, this work has, until recently, largely been confined to the production of macroalgae alongside marine cage fish farming as a method of bioremediation or, as in the Scottish Enterprise Seaweed Anaerobic Digestion (SAD) programme, utilisation of natural standing stocks of seaweed. There is however, an increasing interest into the farming of seaweed in the UK, with interest from the Crown Estate[27] and Whitby Council[28] amongst others. Under the Energetic Algae Interreg IVB project (2011-2015); a pilot scale seaweed plant will be established in Northern Ireland.

The largest amount of research into conversion of macroalgae in the UK has principally focussed on biomethane production, for example, the Seaweed AD (SAD) programme optimised seaweed AD at

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27 http://www.thecrownestate.co.uk/scotland_bulletin_winter_spring_2011.pdf page 6
28 http://www.scarborough.gov.uk/default.aspx?page=15466

the lab scale[29]. However, there has been some, albeit limited work on the conversion of macroalgae to other biofuels, through both thermochemical and biochemical routes in the SUPERGEN Bioenergy Marine project, and some practical work on conversion of seaweed to biofuels in the Interreg IVA project Biomara[30].

4.2.4 Principal Stakeholders

The development of this collaboration will require the input of four major groups of stakeholders, namely, UK and Norwegian research centres, the Norwegian algal industry, UK and Norwegian fermentation facilities and UK industrial biotechnology developers as shown in Figure 6 below.

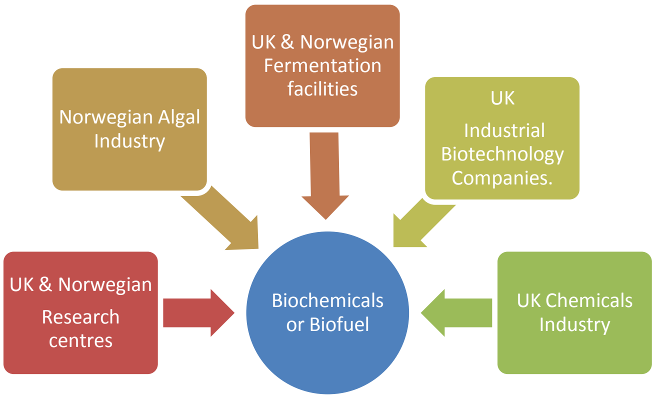

Figure 6 - Major Players in the Development of a Macroalgae to Products Market

Table 1 below summarises the UK and Norwegian industrial and research capability to exploit the use of macroalgae for bulk chemicals. This capability analysis is based on the relative competence of each country and number of stakeholders in each area. The top of each box indicates a competency rating, based on the broad competency of both industry and academic stakeholders in the UK and Norway in each of the underpinning skill areas needed in this collaboration area. At the bottom of the box, we have also given an indicative figure for the number of industrial stakeholders in this collaboration area, by activity area. We have broadly grouped the number of stakeholders in each area into three main groupings, namely, less than ten stakeholders, more than 10 stakeholders and more than 100 stakeholders.

Table 2 - Relative Strengths of the UK and Norway and Number of Potential Stakeholders Underpinning the Production and Utilisation of Macroalgae for Bulk Chemicals

Activity	Industrial Capability		Academic Capability	
	UK	Norway	UK	Norway
Bulk Chemicals	Strong (>100)	Low	Strong	Low
Macroalgae Cultivation and Utilisation	Medium (<10)	Strong (<10)	Medium	Strong
Industrial Biotechnology	Strong (>10)	Low (<10)	Strong	Strong
Fermentation Facilities	Low (<10)	Low (<10)	Strong	Strong

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29 http://www.scotland.gov.uk/Resource/Doc/295194/0115064.pdf
30 http://www.biomara.org/

The key players within each of these sectors and the key skills in the collaboration area are explained further in Section 5.

4.3 Opportunity 3 - Forestry Products for Fuels and Biochemicals

4.3.1 Rationale/Background

Forestry materials are currently used for a wide range of different markets, from paper and pulp manufacture, production of cellulose and wood fuels, panel board production and sawmilling. The Norwegian forestry industry currently accounts for NOK 40.3 bn (£4.0 bn) per year and covers some 40% of the Norwegian land area[31]. While the amount of material felled each year has been stable for the last 80 years, the amount of forestry materials available have been increasing significantly, so that annual growth is three times that of that being felled[32]. This provides a large potential resource for the development of new industries. In addition, there is the potential to add value to side streams of existing industries. Around 1.3 million tonnes of Norwegian wood is used for paper and board manufacture each year. The production of paper and board uses chemical pulping processes, which produce wood components as a side stream. While these are typically used to produce heat and power, declining margins in the pulping industry mean that the forest industry is under pressure to diversity its product range. Converting side streams to chemical products could add value to the pulping operation.

In contrast, only around 12% of the UK is covered in forestry[33]. Around 28% of this resource is owned and managed by the publically funded Forestry Commission[34] but as this resource is already designated for the sawmilling and panelboard industries, there is little chance of using this material for other uses. Unlike Norway, the UK does not have any chemical pulping plants. While the remaining 72% of forestry is privately owned[35], this resource is disparate and the amount of material which could be harvested economically is unknown. The opportunity to utilise UK forestry, at the scales needed for fuels or bulk chemicals production is therefore marginal.

Wood is primarily made up of cellulose, hemicellulose and lignin. Each of these components can be used to produce a multitude of different products. In order to derive full value from wood based materials, new technologies for processing of wood and wood-derived materials are needed. This includes biomass breakdown methods, fermentation technologies, and mechanisms for converting isolated components to value added products. These products could include fermentation based products such as ethanol, succinic acid, lactic acid, butanol and 1, 3 propandiol. In 2010, the global market size for ethanol was around 61 million tonnes, with a market value of around $1,000 per tonne gave a total market size of $61 billion dollars[36]. In contrast, lactic acid had a market size of just over 300,000 tonnes in 2010[37], and with a product price of between $1,300 to $1,600 per tonne gave a total market size of $390 to $480 million while in 2011, succinic acid had a market size of 30,000

[31] http://www.ssb.no/skog_en/

[32] http://www.ssb.no/skog_en/

[33] http://forums.forestresearch.gov.uk/website/forstats2008.nsf/LUContents/4B2ADD432342111280257361003D32C5

[34] Forestry Statistics 2010 - Woodland Areas and Planting http://forums.forestresearch.gov.uk/website/forstats2010.nsf/LUContents/2B1ACBEE309A1CB5802573600034B50D

[35] Forestry Statistics 2010 - Woodland Areas and Planting http://forums.forestresearch.gov.uk/website/forstats2010.nsf/LUContents/2B1ACBEE309A1CB5802573600034B50D

[36] NNFCC (2010) Renewable Chemical Factsheet – Ethanol http://www.nnfcc.co.uk/publications/nnfcc-renewable-chemicals-factsheet-ethanol

[37] NNFCC (2010) Renewable Chemical Factsheet – Lactic Acid http://www.nnfcc.co.uk/publications/nnfcc-renewable-chemicals-factsheet-lactic-acid

tonnes, and with a market price of between 2,000 to 3,000 tonnes had global market value of $60 to 90 million[38]. The demand for bio-based succinic acid is expected to grow significantly in the near future. Deconstruction of lignin could allow the production of phenol chemicals. In 2008, the phenol market was around 8.15 million tonnes, and prices varied from 1,000 to 1,200 per tonne.

4.3.2 Current Activity

There is substantial activity both in the UK and Norway aiming to investigate the use of lignocellulosic materials, predominantly for bioethanol purposes. The technologies used for production of ethanol from lignocellulosic materials could be leveraged for the development of other fermentation-based chemicals. In Norway especially, research on the production of ethanol from lignocellulosics has been investigated as part of a wider biorefinery concept to maximise the value of wood materials. There has been an increasing interest in the UK into developing technologies for adding value to isolated lignin streams.

The UK's flagship research programme in developing technologies for the utilisation of lignocellulosic materials for fuels use is the BBSRC Sustainable Bioenergy Centre (BSBEC) which brings together 12 universities, 14 industrial partners and has a budget of £27 million[39]. Research within the BSBEC programme encompasses a wide variety of projects, from projects aiming to improve feedstock composition for biofuels production, enzyme development for breaking down biomass efficiently to development of strains which can ferment sugars derived from biomass breakdown to both ethanol and butanol. The IBTI programme[40], a £6 million programme, which brings together 10 company members, has so far funded 9 projects. This includes a research project investigating consolidated bio processing of lignocellulosic sugars. Other work within the UK, funded largely though the Renewable Materials LINK scheme (Appendix 4), is looking at exploiting high sugar grasses and cereal straws for the production of bioethanol. Norwegian research in this area has covered the pre-treatment, sugar breakdown and fermentation technologies from wood and from straw products. In many cases, these projects have been closely aligned with the integration of ethanol production with the production of other products as part of an integrated biorefinery.

There is increasing interest in the utilisation of lignin as a chemicals feedstock in the UK. There are a range of projects investigating the breakdown of biomass materials and lignin to produce a range of high value products[41] including aromatic chemicals and fine chemicals. Many of these projects have been funded through the IBTI club. There is some research in Norway in the development of fuels and chemicals from lignin, some of this with UK partners, but this is largely focussed upon pyrolysis of lignin. This contrasts with the focus on catalytic routes of lignin utilisation in the UK.

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[38] NNFCC (2010) Renewable Chemicals Factsheet Succinic Acid. http://www.nnfcc.co.uk/publications/nnfcc-renewable-chemicals-factsheet-succinic-acid

[39] http://www.bsbec.bbsrc.ac.uk/. BSBEC is explained in more detail in Section 6.2 and its constituent projects are outlines in Appendix 5

[40] http://www.bbsrc.ac.uk/business/collaborative-research/industry-clubs/ibti/ibti-background.aspx for more information on IBTI see Section 6.2. Projects relevant to biorefining and industrial biotechnology are given in Appendix 8.

[41] http://web.wimrc.org.uk/wimrc-automotive/projects/major-projects-/wealth-out-of-waste

4.3.3 Hypotheses

Two opportunities could be envisaged:

1. A short to medium term opportunity could exploit the increasing amount of unharvested Norwegian forestry resource. The breakdown of sugars from forestry products could also be used to produce a multitude of chemicals and fuels products via fermentation
2. A longer term strategic opportunity could be based on the processing of lignin products derived from the existing Norwegian pulping industry, to a variety of biochemical products.

These opportunities are shown in Figure 7 below.

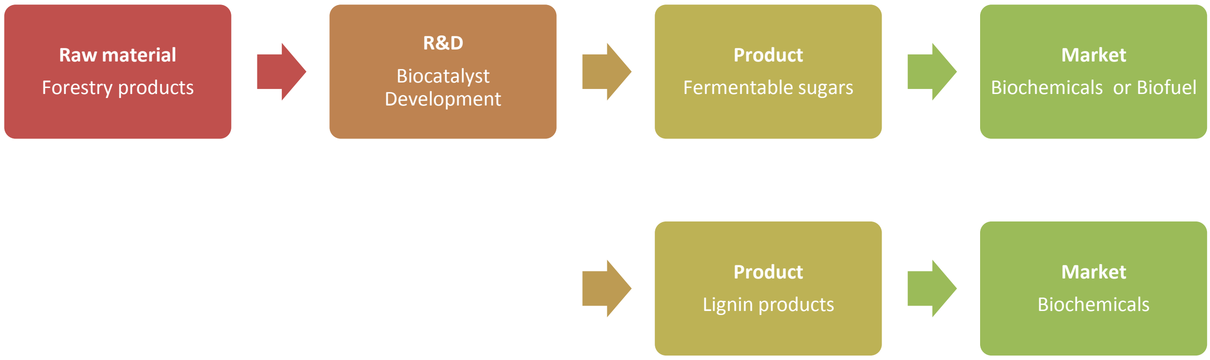

Figure 7 - Production of Bulk Chemicals and Biofuels from Forestry Materials

4.3.4 Principal Stakeholders

The development of this opportunity will require the input of four major groups of stakeholders. Namely, the Norwegian forestry industry, UK and Norwegian fermentation facilities, UK and Norwegian research centres and UK Industrial biotechnology developers (Figure 8).

The key players within each of these sectors and their key skills are explained further in the following section.

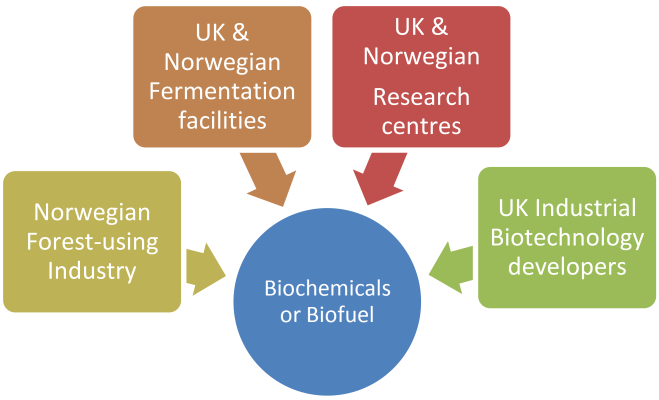

Figure 8 - Collaboration for production of Bulk Chemicals and Biofuels

Table 3 below summarises the UK and Norwegian industrial and research capability to exploit the use of forestry for bulk chemicals. This capability analysis is based on the relative competence of each country and number of stakeholders in each area. The top of each box indicates a competency rating, based on the broad competency of both industry and academic stakeholders in the UK and Norway in each of the underpinning skill areas needed in this collaboration area. At the bottom of the box, we have also given an indicative figure for the number of industrial stakeholders in this collaboration area, by activity area. We have broadly grouped the number of stakeholders in each area into three main groupings, namely, less than ten stakeholders, more than 10 stakeholders and more than 100 stakeholders.

Table 3 - Relative Strengths of the UK and Norway and Number of Potential Stakeholders Underpinning the Utilisation of Forestry for the Production of Bulk Bio based Chemicals.

Industrial Activity	Industrial Capability		Academic Capability	
	UK	Norway	UK	Norway
Bulk Chemicals	Strong (>100)	Medium	Strong	Medium
Forestry Using Industry	Low (<10)	Strong (<10)	Weak	Strong
Industrial Biotechnology	Strong (>10)	Low (<10)	Strong	Strong
Fermentation Facilities	Low (<10)	Low (<10)	Strong	Strong

The key players within each of these sectors and the key skills in the collaboration area are explained further in Section 5.

4.4 Opportunity 4 – Processing of Marine Wastes to Products

4.4.1 Rationale/ Background

The sea fisheries industry produces a range of fish, crustacean and mollusc species. Over 12.8 million tonnes of sea fish products were caught by European area owned vessels in 2009, with some 5 million tonnes of this within the European Union. Both the UK and Norway have extensive coastlines and a strong maritime tradition. In terms of material landed, Norway was the second largest sea fisheries economy in the European area in 2009[42]. Norway landed some 2.5 million tonnes (fresh weight) of fish, with the industry worth some 11.3 bn NOK (around £ 1.13 bn)[43]. The UK industry is substantially smaller, the 5th largest in Europe and landed some 0.59 million tonnes (fresh weight), and the industry was worth around £0.67 bn)[44].

The sea fisheries industry is undergoing consolidation and margins are tight. This situation is exacerbated by increasing waste disposal costs and increasingly tight environmental disposal regulations. The sea fisheries processing industry produces a large amount of waste materials, including trimmings, fins, skins, muscles, shells and bones. It is estimated that globally, around 20 million tonnes of material is discarded from the fisheries industry, equivalent to around 25% of the catch[45]. Traditionally, these wastes have used in the production of low value products including fertilisers, fish meal, fish oil and pet foods[46]; however there has been an increasing interest in using by products from the sea fish processing industry as a source of higher value bioactive compounds. Fish skin waste for example, could be used as source of collagen and gelatin. These are both currently used in a wide range of food, cosmetic, and biomedical applications[47]. The market for gelatin was 326,000 tonnes in 2009. The isolation of these products from process waste could therefore improve the economics of fish processing.

4.4.2 Hypothesis

Both the UK and Norway produce substantial amounts of marine by products as a result of sea fish processing. Bioactive compounds within marine by products, discovered by Norwegian researchers could be used by the UK consumer goods producers. These products could be used by the UK consumer goods companies which are innovative and constantly looking for new ingredients to provide product differentiation.

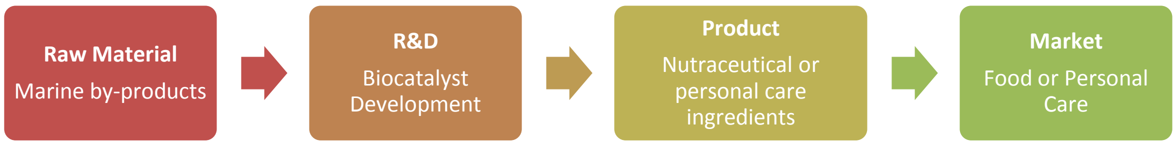

Figure 9 – Opportunity 4 - Bioactive Molecules from Marine to be used in the UK Consumer Goods Marke

42 http://www.marinemanagement.org.uk/fisheries/statistics/annual2009.htm#ch6
43 http://www.ssb.no/english/subjects/10/05/fiskeri_en/
44 http://www.marinemanagement.org.uk/fisheries/statistics/annual2009.htm#ch6
45 Rustad, T (2003) Utilisation of Marine By Products. http://ejeafche.uvigo.es/index.php?option=com_docman&task=doc_view&gid=201
46 Mining Marine Shellfish Wastes for Bioactive Molecules: Chitin and Chitosan – Part A: Extraction Methods. Biotech Journal 2008 3: 871-877.
47 Bioactive compounds from marine processing by products – A review. Food Research International. 39 (2006) 383-393.

4.4.3 Current Activities

Norway has a number of projects underway aiming to add value to marine by products from the sea fish processing sector. These include a project investigating the health benefits of using a minimally processed protein powder in foods, the potential to use salmon by products as a growth material for probiotic bacteria, the potential for hydrolysed fish protein to lower cholesterol, the development of high omega 3 oils and seafood flavours from by products, and the use of marine by products as an aquaculture feed.

4.4.4 Principal Stakeholders

The development of this opportunity will require collaboration between four groups of stakeholders, the Norwegian and UK research centres, the Norwegian marine products industry, UK consumer goods industry and the UK industrial biotechnology industry as shown in Figure 10 below.

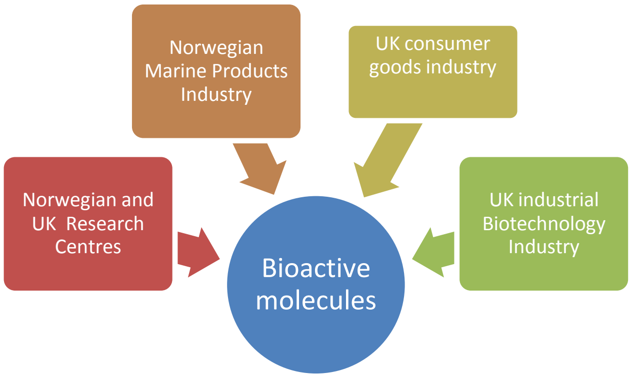

Figure 10 - Major players in the Development of Bioactive Industry

Table 4 below summarises the UK and Norwegian industrial and research capability to exploit the use of sea fish processing wastes for the production of high value speciality chemicals for the UK consumer goods industry. This capability analysis is based on the relative competence of each country and number of stakeholders in each area. The top of each box indicates a competency rating, based on the broad competency of both industry and academic stakeholders in the UK and Norway in each of the underpinning skill areas needed in this collaboration area. At the bottom of the box, we have also given an indicative figure for the number of industrial stakeholders in this collaboration area, by activity area. We have broadly grouped the number of stakeholders in each area into three main groupings, namely, less than ten stakeholders, more than 10 stakeholders and more than 100 stakeholders.

Table 4 - Relative Strengths of the UK and Norway and Number of Potential Stakeholders Underpinning the Utilisation of Sea fish Processing Wastes for Speciality Chemical Applications.

Industrial Activity	Industrial Capability		Research Capability	
	UK	Norway	UK	Norway
Speciality Chemicals	Strong (>100)	Low	Strong	Medium
Marine Products	Low (<5)	Strong (>10)	Low	Strong
Industrial Biotechnology	Strong (>10)	Low (<10)	Strong	Strong

The key players within each of these sectors and the key skills in the collaboration area are explained further in Section 5.

5 UK and Norwegian Capabilities in Industrial Biotechnology or Biorefining

This section builds upon the identified opportunities in Section 4 and highlights some of the expertise and resources that either the UK, Norway or both countries could bring to a collaborative venture. These have been classified into renewable raw material resources, technology development expertise and markets.

5.1 Renewable Raw Materials

5.1.1 Marine By-Products

Both the UK and Norway have extensive coastlines and a strong maritime tradition. Processing wastes account for around a quarter of all fish caught and farmed. While some of the by products from the fish processing industry are used for the production of oils and feed for the aquaculture industry, significant quantities are disposed of. A wide range of higher value products could be made from marine bio actives, including cosmoceuticals, nutraceuticals, enzymes and pharmaceuticals. Chitin, extracted from the shells of prawns and crabs are expected to have a market value of $63 billion by 2015, and of this, chitosan is estimated to have a market value of $21.4 billion in the same period[48].

Norway has a considerable interest and capability in the processing of fish industry wastes to value added products. The RUBIN Foundation[49] works towards maximising value of the by products from fish farming and fisheries industries and the total utilisation of sea fish. In 2010, the RUBIN Foundation had funded 7.5 million NOK of projects[50]. NOFIMA and SINTEF have programmes to identify bioactive components from fish industry wastes whilst the NOBIPOL group at NTNU are investigating the isolation and potential industrial uses of chitosans from shrimp waste, and the potential for using gelatins from fish as encapsulation agents. Aqua Bio Technologies ASA, have worked with NTNU and developed gels from fish collagen.

There are a number of companies which utilise marine waste material. A large proportion of these companies produce fish oils, meals, silage and protein for the aquaculture industry. This includes Scanbio, Zymtech Products AS, Marine Bioproducts AS, NutriMar, BioMega and Seagreen. There are also a small number of companies using fish processing wastes for the development of higher value products. Norwegian Chitosan, Chitinor and Advanced Biopolymers, for example isolate and market chitosan products for a variety of end markets including cosmoceuticals, nutraceuticals, pharmaceuticals, and various industrial applications including paper production. Aqua Bio Technologies ASA, has developed a skin exfoliation ingredient from salmon hatching fluid while Calanus AS are developing products from *Calanus finmarchicus,* a marine crustacean.

There appears to be considerably less activity in the processing of fish industry wastes in the UK, and what research there is appears sporadic and uncoordinated. Glyndwr University are investigating methods for extracting chitin from prawn shells and then chemically modifying it to produce

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[48] Cosgrove (2010) The Global Chitosan Market http://www.nutraceuticalsworld.com/contents/view/30300
[49] http://www.rubin.no/eng/
[50] Bekkevold, S (2011) RUBIN Foundation. Personal Communication to Claire Smith, 14th June 2011.

chitosan and chitosan derivatives while University of York have a research programme on using chitosan as a catalyst support. Queens University Belfast a research programme on krill oil isolation. The EXCIL project 'Selective Extraction of Valuable Food Processing Components using Ionic Liquids' is a TSB funded project[51] which is aiming to identify valuable products from seafood processing waste and brewery wastes. Archimedes Development in Nottingham have developed a range of chitosan containing products for intranasal delivery applications. The Humberside Seafood Institute is a £5.9 million funded facility which supports seafood and seafood logistics companies in the UK, and they could develop research into identifying value added products from marine by products.

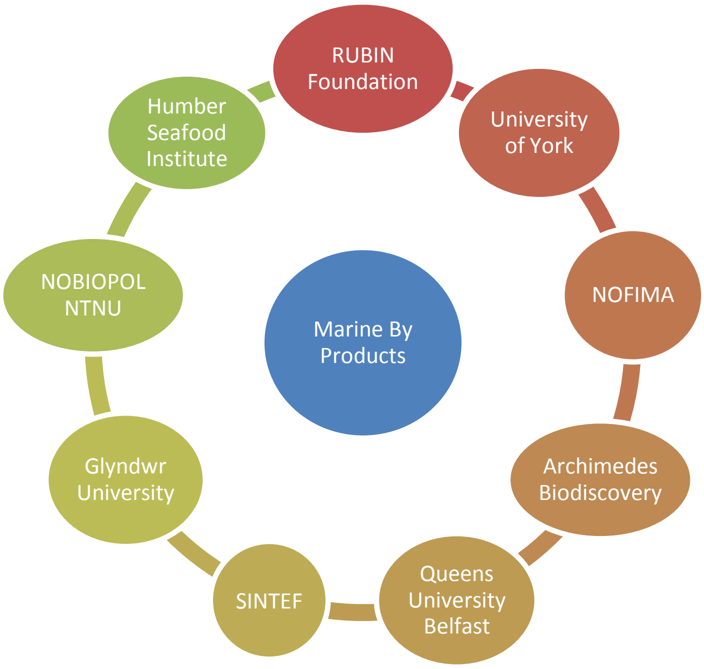


Figure 11 - Key Players for the Exploitation of Marine by Products in the UK and Norway

5.1.2 Algae and Marine Microbes

1. Macroalgae

Both the UK and Norway have extensive and highly indented coastlines with cool waters amenable to the growth of seaweeds. Seaweeds, especially brown seaweeds, grow extremely well in the UK and Norway. Estimates of the amount of seaweed stocks available in the UK and Norway are highly variable and are often based on surveys of limited geographical areas. The Norwegian standing stock of macroalgae was estimated to be 10 million tonnes in 1998[52]. It is suggested that Scotland has a similar standing stock of macroalgae as Norway. Surveys of the standing stocks of macroalgae in

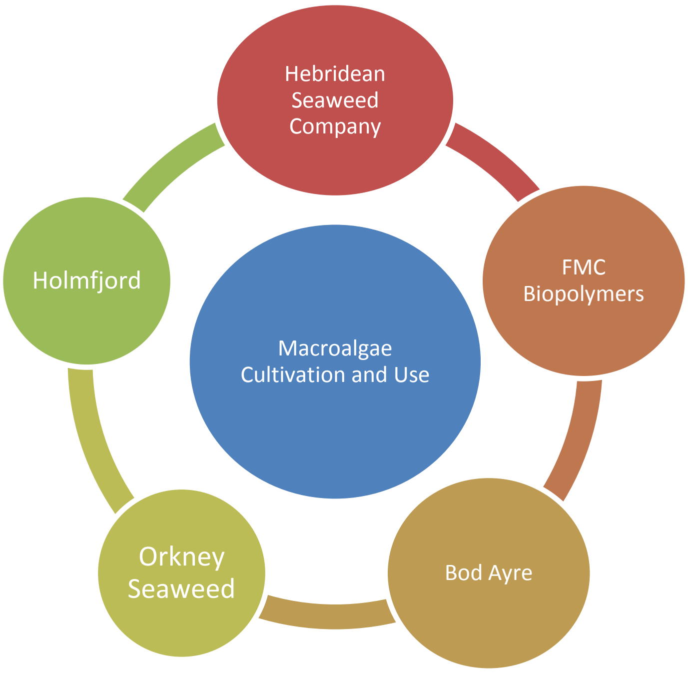
[51] http://www.excil.net/index.php
[52] Jensen as quoted in Sustainable Energy Ireland Report (2009) http://www.sei.ie/algaereport

Scotland were undertaken as part of the Seaweed Anaerobic Digestion programme funded by Scottish Enterprise in 2010[53].

The UK macroalgae industry is small and consists of around three small scale companies, Hebridean Seaweed Company, Orkney Seaweed, and Bod Ayre, all of which are based in Scotland and all of which utilise wild stocks of algae (predominantly *Ascophyllum nodosum*). The scale of macroalgae harvesting in the UK is not known, but is not expected to exceed 10,000-15,000 tonnes per annum, given that the Hebridean Seaweed Company harvest around 5,000 tonnes per annum[54]. All of these companies use the seaweed for the production of liquid fertiliser and livestock feed. Scotland has, historically had an alginate extraction industry, but this closed in the late 1990's.

In contrast, the Norwegian macroalgae industry is larger with around 130,000-180,000 tonnes of algae used for the production of alginates by FMC Biopolymers who manufacture high quality food and pharmaceutical grades of alginates from *Laminaria hypoborea*. In 2009, around two-thirds of the European production of 8,900 tonnes of alginates was produced in a single facility in Norway[55]. A further 10,000-20,000 tonnes of *Ascophyllum nodosum* algae is used for the production of seaweed meal.

Both the UK and Norway currently harvest wild stocks of algae for industrial use either by hand or through mechanical methods, but it is generally acknowledged that for larger scale industrial uses, farming of algae will be needed. UK and Norwegian capability in developing methods for large scale cultivation of algae are indicated in section 5.2.2.



53 James, MA (2010) A review of initiatives and related R&D being undertaken in the UK and internationally regarding the use of macroalgae as a basis for biofuel production and other non-food uses relevant to Scotland. Report commissioned by Marine Scotland. 79pp.

54 James, MA (2010) A review of initiatives and related R&D being undertaken in the UK and internationally regarding the use of macroalgae as a basis for biofuel production and other non-food uses relevant to Scotland. Report commissioned by Marine Scotland. 79pp.

55 Bixler, H.J., Porse, H (2010) A decade of change in the seaweed hydrocolloids industry. Journal of Applied Phycology. http://www.algaebase.org/pdf/AC100CF011cce16156PIqW9AFCE2/Bixler_Porse.pdf

2. Microalgae

Both Norway and the UK have cool climates with limited space and sunlight. This raises questions about whether it would be feasible to achieve year round cultivation of microalgae at sufficient scale for bulk end markets such as fuels, although both countries could ostensibly develop technologies to be developed in more favourable locations around the world. There is however, a greater potential to grow microalgae for lower volume markets such as for speciality ingredients in photo bioreactors, especially if combined with bioremediation of waste waters, carbon dioxide or heat.

The UK has a number of small-scale photobioreactors for microalgae growth. Microalgae are commercially produced for aquaculture purposes at Seasalter Whitstable and a facility in Barrow, Cumbria. Boots and PML have developed a 32,000 litre photobioreactor at Nottingham using CO_2 emissions from a combined cycle gas turbine power station, with the intention that the microalgae will be used for high value products. There are photobioreactors at Swansea University and Varicon Aqua to produce algae for aquaculture and Exalga to produce microalgae for aquaculture and high value products. Durham University have a 400 litre tubular photobioreactor which is used for research into the production of algal lipids for biodiesel production. Until recently, there was a photobioreactor at the Glenturret distillery in Scotland which utilised copper rich waste water from the Scotch whisky industry and CO_2 emissions from an on-site power station. There are plans to develop an Algal Innovation Centre from 2014 at a site near Cambridge, led by InCrops in the UK, which will showcase a variety of bioreactors, raceway ponds and fermentation systems[56] part funded through the Interreg IVB Energetic Algae project.

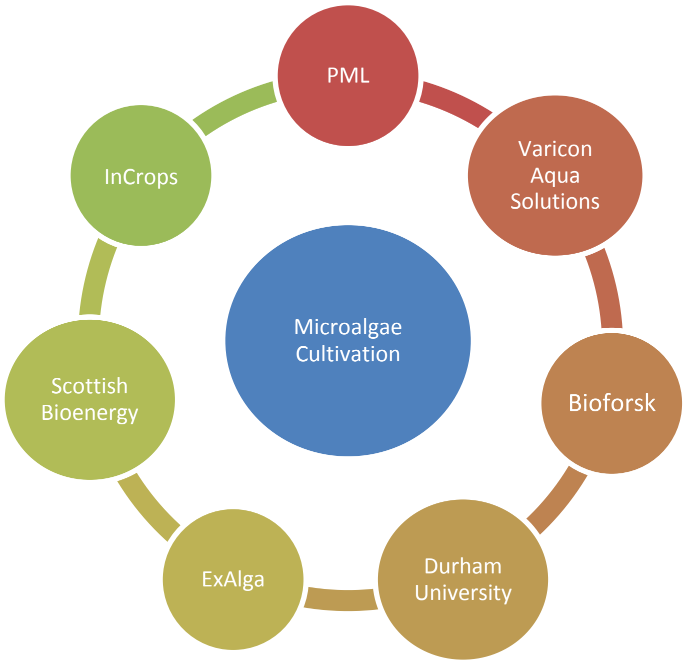


Figure 12 - Key Players for Microalgae Cultivation Expertise in the UK and Norway.

[56] Personal Communication with Beatrix Schlarb-Ridley, InCrops.

5.1.3 Marine Microbes and Organisms

The marine bio prospecting industry is based on the effective 'mining' of marine organisms to identify novel traits. As such, collections (or 'biobanks') of marine organisms are considered key to the development of this sector. Both the UK and Norway have bio banks of marine organisms and genetic material which would underpin the development of this sector.

UK capability appears to be based around algae, bacteria and protozoa, with collections at the Marine Biological Association, Plymouth, National Collection of Industrial, Food and Marine Bacteria (NCIMB), Aberdeen, the Culture Collection of Algae and Protozoa at Oban. CABI have taken over the British Antarctic Survey collection of microorganisms and this may include some marine species.

Norwegian capability appears to be broader, with the Marbank at the Centre for Marine Bioactives and Drug Discovery at the University of Tromso, acting as the national repository for biological and genetic information from plankton, algae, invertebrates and vertebrate species. The University of Bergen centre of excellence in geobiology, has isolated species from hydrothermal plumes, sulphide deposits, mud volcanoes and other extreme environments. These are kept at Bergen Marine Biobank. NIVA, the Norsk Institutt for Vannforskning in Oslo has a culture collection including microalgal isolates.

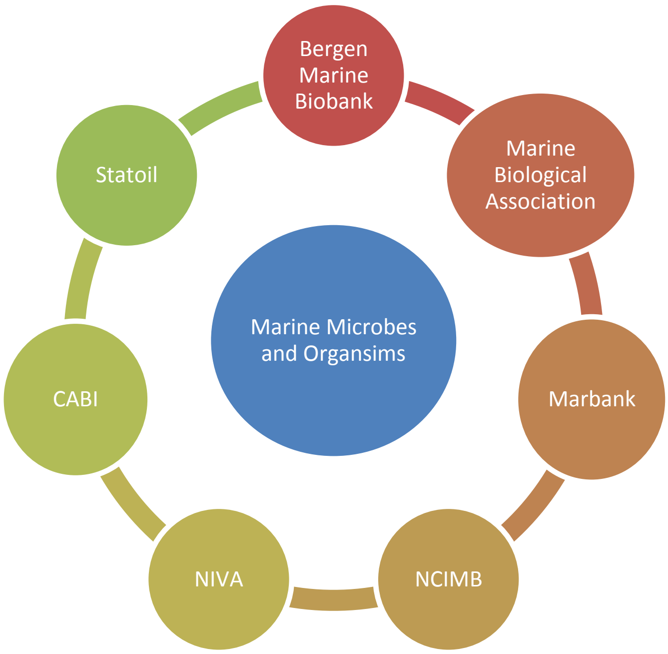


Figure 13 - Key Players in the UK and Norway with BioBanks of Marine Microbes and Organisms

5.1.4 Forest Industry

With around 40% of its land area covered in forest in 2009, it is perhaps unsurprising that Norway has developed an extensive and vibrant forestry industry. In 2009, Norwegian forestry industry accounted for 0.6% of GDP employing some 4,100 people. Norwegian forestry is dominated by three main species, Norway Spruce (47%), Scots Pine (33%) and Birch (18%). Norway has significant advantages in terms of biomass availability for developing a forestry based biorefinery. This is because:

1. Forest policy has resulted in large increases in standing volumes, well in excess of current usage. This material forms a significant resource on which a forestry based biorefinery could be based and would not impact upon existing wood markets
2. Norway has a mix of different forestry enterprises, including sawmilling, panelboard manufacture and pulp and paper manufacture. Indeed one of the largest industries in Norway is the pulp and paper industry, with 33 companies in this sector. In 2002, pulp and paper making generated around NOK 20 bn (£ 2 billion) revenue.

Statskog is a state owned enterprise which has interests in sustainable land use. Around 15% of Statskog's interests are forestry, of which a third of this is productive forestry[57].

As well as untapped biomass resources for biorefining and industrial biotechnology, Norway has developed a considerable research and industrial strength aligned to forestry and the industrial utilisation of forestry resources. The Norwegian Forest and Landscape Institute and Bioforsk, both in As, are national centre of expertise in sustainable utilisation of land and forestry resources. UMB performs underpinning R&D on forest science. Treteknisk is a private research association for wood industry in Norway with 150 members representing a wide range of wood markets.

There is more specific expertise in paper and pulp manufacture in several areas. The Paper and Fibre Research Institute have expertise along the whole value chain from wood to the development of fibre based products. PFI have worked on a wide range of different projects looking at how wood can be used for the production of novel industrial products, looking at pre-treatment and separation technologies, material quality, and how lignocellulosic materials can be converted to biofuels and other value added products. The NTNU paper and pulp group work extensively with PFI.

Borregaard produce speciality cellulose from wood and a range of biobased chemicals from wood. Based in Norway, they are a major player in the pulp and paper industry internationally. International companies such as Sodra Cell also have operations in Norway, with mills at Tofte and Folla. Other players in the paper and pulp industry in Norway include Norsk Skog who is the largest pulp and paper company in Norway and Peterson Linerboard AS, a packaging company.

[57] http://www.statskog.no/en/Documents/070510_trykksak_strategi_engelsk.pdf

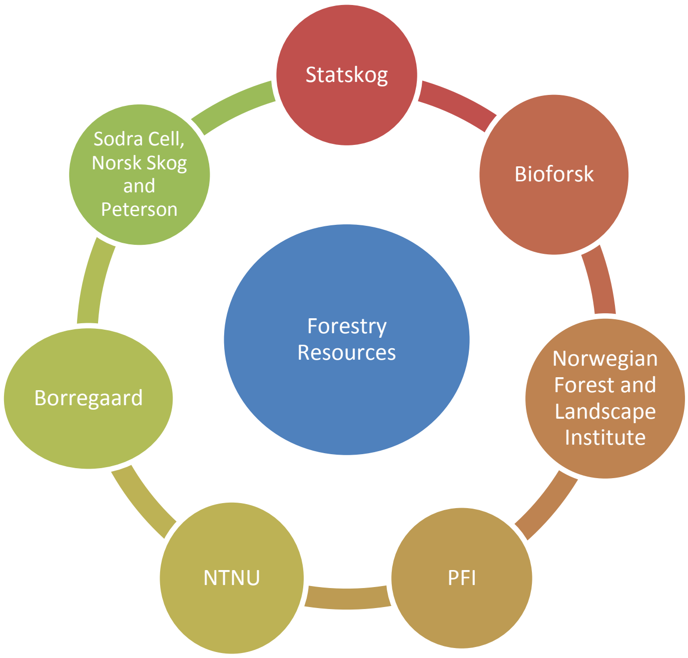


Figure 14 - Key Players in the Norwegian Forest Industry

5.2 Technology Areas

5.2.1 Biocatalysis

Biocatalysis is the use of natural catalysts to perform chemical transformations. Biocatalysts have a number of potential advantages over conventional catalytic processes, including high specificity with fewer waste products, higher yields, mild reaction conditions and low environmental impacts. Realising new opportunities for Industrial Biotechnology is partially dependent on the development of new and novel biocatalysts.

Both Norway and the UK have research centres with programmes to develop knowledge on biocatalysts. General underpinning expertise in biocatalysis in the UK is provided through the Centre of Excellence for Biocatalysis, Biotransformations and Biocatalytic Manufacture (CoEBio 3) at Manchester University. The University of Bristol, Exeter University and the University of St Andrews all have underpinning expertise in elucidating the structure function relationships of biocatalysts. Similarly, Norway has strong capabilities on the structure determination through the Norwegian University of Life Science (UMB), Norstruct and SmallStruct. NorStruct is the national research service and service centre focussing on protein structure whilst SmallStruct focuses on the determination of small molecule determination.

More specialised biocatalysts relevant to the opportunities identified in this report are biocatalysts derived from extremophiles and lignocellulosic degradation biocatalysts.

Industrial applications can benefit from biocatalysts capable of operating under a range of conditions including low or high temperatures, low or high pH, high salt concentration and high pressure. Extremophile organisms, for example those originating in highly saline environments and thermal vents can provide a source of such biocatalysts. The search for such novel functionalities is therefore greatly dependent on both the bio banks and marine bio prospecting capabilities discussed in sections 5.1.3 and 5.2.5. There is expertise in the isolation and exploitation of biocatalysts from extremophile organisms in both Norway and the UK. In Norway, SINTEF Materials and Chemistry have a Centre for Extremophiles whilst the UK has the Centre for Extremophile Research at the University of Bath. Biocatalysts identified from extremophile organisms could be used in a wide range of applications, including the breakdown of marine by products, lignocellulosic materials and use in the production of industrial products such as those used by the consumer goods industry.

The exploitation of lignocellulosic and algal biomass for biofuels will depend on the effective breakdown of these biomass sources to enable fermentation of their sugars. The UK and Norway both have activities in this area. The University of York have a research programme on marine wood borers funded through the BBSRC Sustainable Bioenergy Centre while Mycologix, a spin out from Imperial College, London, are developing brown rot fungal strains for the breakdown of lignocellulosic materials. UMB in Norway have a particular capability in the discovery of enzymes for biomass deconstruction and have identified a completely new class of cellulose degrading enzymes.

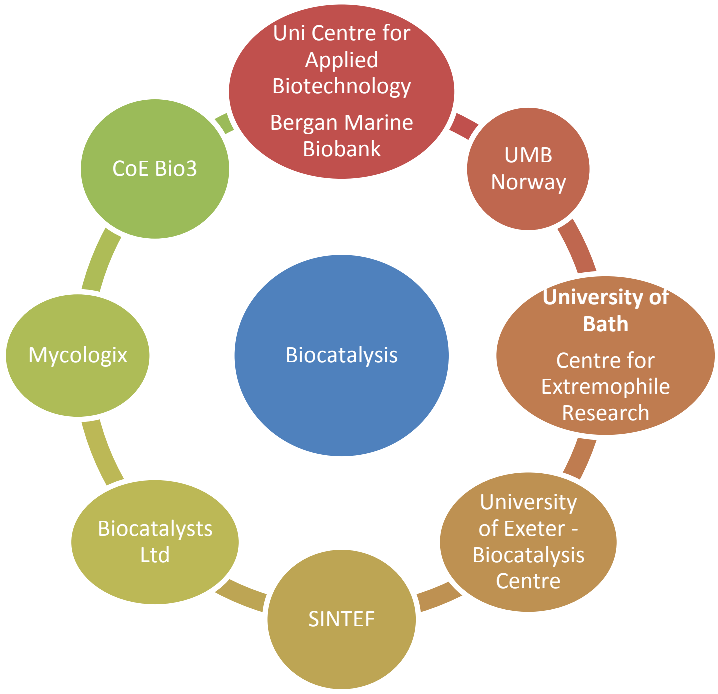


Figure 15 - Key Players in the Development of a Biocatalysts Industry

5.2.2 Macroalgae Cultivation

Expertise in macroalgae cultivation in the UK is limited to a handful of organisations. This includes Scottish Association for Marine Sciences, Plymouth University and Queens University Belfast. In Norway, the principal establishments in this area are NTNU and SINTEF.

Scottish Association for Marine Sciences (SAMS), University of Plymouth and SINTEF and NTNU have an interest in developing macroalgae farms in conjunction with aquaculture enterprises in a process known as Integrated Multitrophic Aquaculture.

Some small scale trials of macroalgae growth have been carried out in the UK and Norway adapting rope line technologies from the aquaculture industry. Scottish Association for Marine Sciences have performed a number of small scale trials (<1 ha) on long lines in Scotland in conjunction with aquaculture enterprises, while Viking Fish Farms in Scotland have a macroalgae hatchery for seeding macroalgae plantlets onto ropes which are subsequently grown in Loch Duart[58]. There are plans for the development of a small scale macroalgae farm in Northern Ireland as part of the Interreg IVB Energetic Algae project, and the UK Crown Estate, which owns the seabed around the UK have established a working group to promote the development of a macroalgae farm in the UK.

Seaweed Energy Solutions in Norway have pioneered the development of an innovative seaborne structure to allow the farming of macroalgae on an industrial scale. Statoil have experience of growing macroalgae in their aquaculture operations and have plans to develop a macroalgae to ethanol operation through their collaboration with Bioarchitecture Lab in Norway, once the technology is developed.

[58] Kenny Black, SAMS, personal communication 23rd May 2011.

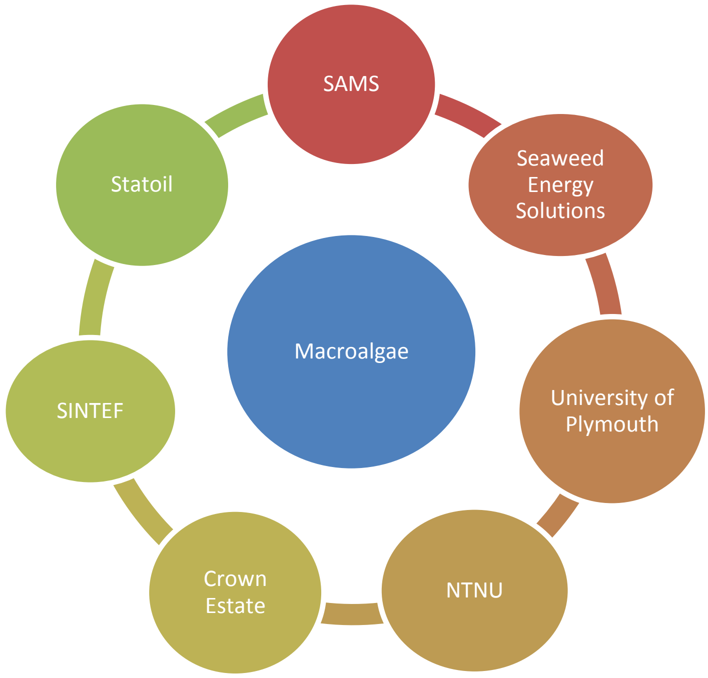


Figure 16 - Key Players in the Development of a Macroalgae Industry

5.2.3 Microalgae Utilisation

The UK has strength in the development of microalgae cultivation equipment and in researching how microalgae can be grown. There are a number of companies developing photobioreactor technologies, including Varicon Aqua, ExAlgae, Scottish Bioenergy, and photobioreactor.co.uk, a spin out from Plymouth Marine Labs. The last three are developing integrated systems combining algae growth with waste stream remediation. Underpinning research on algal growth systems is also strong in the UK with research at Plymouth Marine Labs, Heriot Watt University, Sheffield University, Loughborough University, University College London all studying photobioreactors. Cranfield University's Offshore Algal Supplier Infrastructures (OASIS) programme is establishing a pilot facility for the production of microalgae biofuel and this will be followed by the development of an offshore facility in the southern North Sea[59].

In Norway, Uni Research are taking a leading role in a feasibility study on using waste heat and captured CO_2 from Technology Centre Mongstad, and will explore different strategies for biomass utilisation including use for fuels, aquaculture feed, marine oils, pigments and nutraceuticals. NoBio – Norsk Bioenergiforening, are working with Swansea University, Varicon Aqua and several other UK and European partners in the BioAlgaeSorb project which aims to investigate how microalgae growth could be combined with effluent water remediation and CO_2 capture.

[59] http://www.oasisnetwork.co.uk/downloads/OASIS-Network-BioFuel.pdf

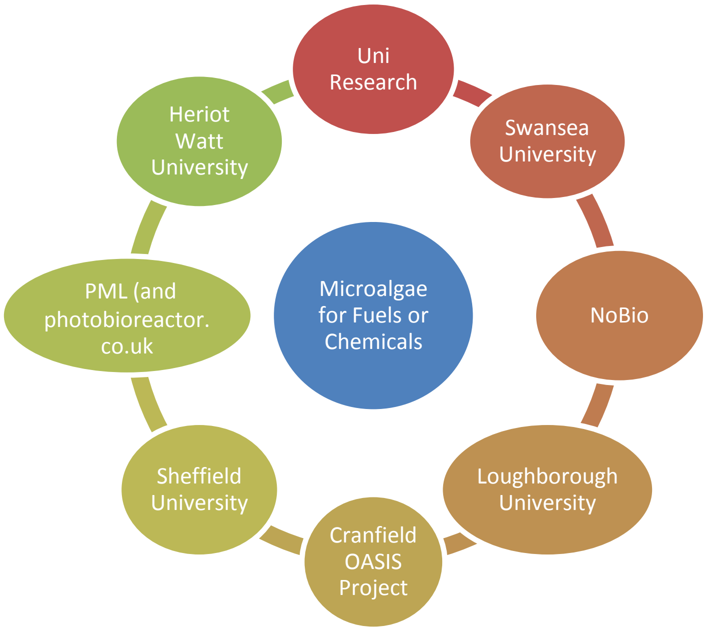


Figure 17 Key Players for the Development of Macroalgae Farming Operations in UK and Norway

5.2.4 Microbial Strain Development and Fermentation Facilities

Both the UK and Norway have strengths in industrial biotechnology which could be used to develop fermentation based chemicals from macroalgae.

The UK capability in the development of microbial strains for fermentation processes is on par with leading countries world-wide. The UK has particular strengths in the development of microbial strains which can ferment C5 sugars in lignocellulosic materials to ethanol. There is expertise in fermentation of C5 sugars to ethanol at University of Ulster, Imperial College, Bath University and Nottingham University. There is expertise in the development of organisms for bio butanol production at Nottingham University and Napier University. The UK also has a number of innovative companies in this area, particularly TMO Renewables and Biocaldol who are developing thermophillic organisms who can ferment C5 sugars to ethanol, Green Biologics who are working on the manipulation of the ABE process to enhance butanol yield, and Kingston Research Limited who are developing a bio butanol technology process which will be commercialised by Butamax Advanced Fuels. To our knowledge, with the exception of Napier University, all are developing their technologies on terrestrial lignocellulosic biomass only.

Norway also has impressive strengths in the development of microbial strains for fermentation, with expertise at SINTEF Materials and Chemistry and UMB on fermentation optimisation and development and the development of genetically engineered microorganisms for the fermentation of xylose.

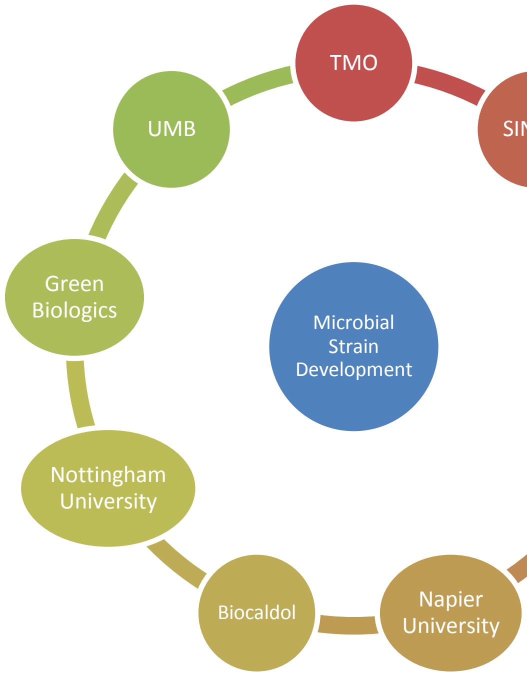


Figure 18 - Key UK and Norwegian Players in Microbial Strain Development for Fermentation

Both the UK and Norway have impressive fermentation facilities which could be utilised for testing the efficiency of microorganisms in producing products. Both IRIS Biocentrum in Norway and the Centre for Process Innovation (CPI) National Industrial Biotechnology Facility in the north east of England have capabilities to take products from the bench scale, through pilot scale to demonstration scale, with the largest fermentor at NIBF at 10,000 litres, while IRIS has a fermentor at 30,000 litres. Other fermentation scale facilities are generally at the lab or pilot plant scale. At the lab scale, SINTEF have 32 x 3 litre fermentors and 3 x 14 litre fermentation facilities. At the pilot scale, SINTEF have 300 and a 1,500 litre fermentors, while the University of Nottingham in the UK are developing a 1,000 litre fermentor which will be operational in 2011.

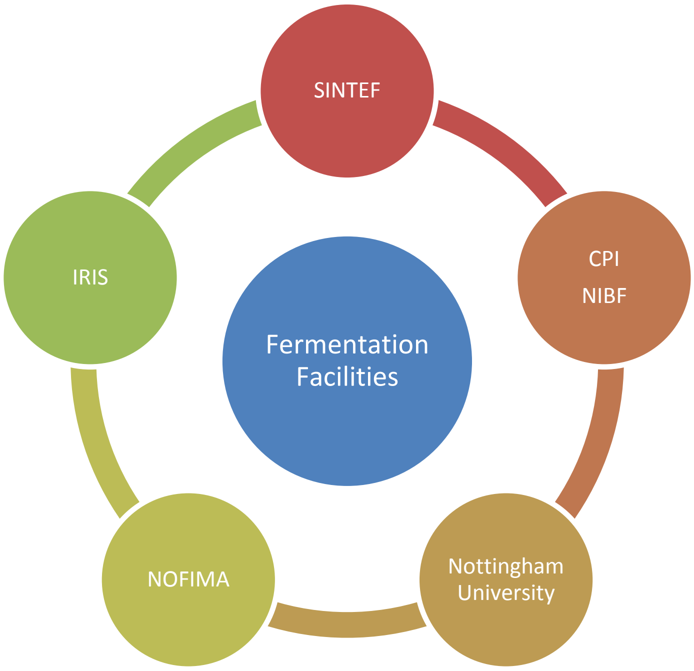


Figure 19 - UK and Norwegian Fermentation Facilities

5.2.5 Marine Bioprospecting

Marine bio prospecting is the search for bioactive compounds in marine organisms. The use of these compounds for industrial and pharmaceutical purposes forms the area of marine biotechnology. Bioprospecting transcends all three of the technology areas mentioned above, and given the importance of marine bioprospecting in developing a UK Norway collaboration, the skills and competencies of both countries in this area has been identified separately.

The world sales of marine biotechnology related products are estimated to reach $ 4.1 billion by 2015[60]. Norway has a significant academic and industrial R&D strength in bio prospecting. Norway has over 20 years activity in this area and, through favourable Government support of this sector, capabilities and capacities in this sector has grown. The Norwegian government have implemental a national strategy entitled "Marine Bio-prospecting – a Source of New and Viable Wealth Creation". The program which runs to 2020, aims to strengthen infrastructure and networking to realise opportunities from Norway's marine genetic resources. An initial 50 million NOK (~£5.7 million) was allocated to the program in 2010.

"Norwegian research into the unique biodiversity of the Arctic waters is already leading to the discovery of many molecules, such as unique metabolites with pharmaceutical potential and cold-adapted enzymes with important industrial applications"

Kjersti Gabrielsen, Head of Marbank

The identification of marine bioactive molecules is carried out at the Marine Biodiscovery Centre at the University of Aberdeen, Plymouth Marine Labs and at the Scottish Biological Resource Centre (SBRC), a joint venture between SAMS and Drug Discovery Ltd. Wider work on bioactive molecule identification is carried out by CABI who have formed a number of strategic research alliances to

[60] http://www.pml-applications.co.uk/global_marine_biotech_news.aspx

identify active products in biological materials, for example they are working with the British Antarctic Survey to explore their collection of microorganisms for bioactive molecules. The recently opened Astec Centre in the North East of England is investigating the potential to use invertebrates such as sponges as medicine sources, and whether marine bacteria can be used for nutraceuticals[61].

Marbio in Norway have expertise in screening for bioactive molecules with anti-bacterial, anti-inflammatory, anti-diabetic, anti oxidants, and anti-cancer activities and NOFIMA have a lab scale bioactivity screening capability focussed on the identification of bioactive materials from marine waste material. Norwegian bio banks contain arctic and thermal species making them a unique resource for bioactive molecule identification. The key stakeholders in the development of a marine bioprospecting industry are indicated in Figure 20 below.

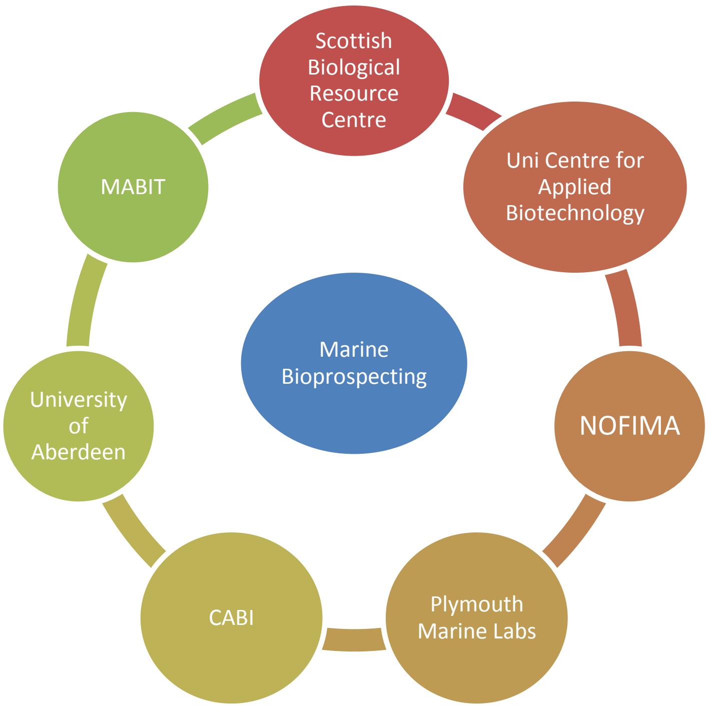


Figure 20 - Key Players in the UK and Norway for the Development of a Marine Bioprospecting Collaboration

5.3 Markets

5.3.1 UK Chemicals Industry

The production of chemicals and chemical products accounts for 12% of all UK manufacturing. The industry provides 214,000 direct jobs and supports a further several hundred thousand indirectly. The UK chemical industry covers the production of commodity, speciality and consumer chemicals. The 3,125 chemical companies in the UK supply 95,000 different chemicals and chemical products and produce 2.5 million tonnes of plastic per year.

[61] Hill, J (2011) New North East Base to Aid Research. The Journal. May 26th 2011. http://www.nebusiness.co.uk/business-news/science-and-technology/2011/05/26/new-north-east-base-to-aid-research-51140-28768034/

5.3.2 Bulk Chemicals

Bulk chemical production is one of the largest in the UK chemicals sector with an annual turnover of £18.4 billion, and comprising of around 885 companies[62]. These companies produce industrial gases, fertilisers, rubber, man-made fibres, organic chemicals such as ethanol and inorganic chemicals. Bulk chemical manufacturing in the UK is primarily around four clusters, Teesside, Grangemouth, North West and Yorkshire and Humber. All of these locations have easy port access, and although the existing infrastructure is based on petrochemical products, there is an increasing interest in the production of bio-based products in these areas too, for example the Ensus and Vivergo wheat to ethanol plants are based on Teesside and Humberside respectively. Leading players in the UK bulk chemicals industry include Ineos, Shell Chemicals and BP.

A study by Nexant for NNFCC identified the key biobased chemicals which the UK could produce, and was based on an assessment of the market potential for these products and whether the UK could compete in an international market and provide a realistic return on investment in these areas[63]. The identified opportunities were:

1. Propylene glycol produced from glycerine
2. γ- buytyrolactone (GBL) from glucose via succinic acid
3. Linear low density polyethylene (LLDPE) from bioethanol derived ethylene
4. High density polyethylene (HDPE) from bioethanol derived ethylene
5. Tetrahydrofuran (THF) from glucose via succinic acid
6. Tetrahydrofuran (THF) via fumaric acid
7. Succinic or Fumaric acid from glucose
8. 3 – hydroxypropionic acid (3 HP) from glucose
9. Methyl methacrylate (MMA)
10. Polyhydroxyalkanoates
11. Lactic acid from glucose and conversion to polylactide

In addition butanol is an attractive opportunity for the UK. Many of these opportunities are based on fermentation of sugars, with lactic acid, fumaric acid, succinic acid, and bioethanol as key intermediates. Compounds such as ethanol, succinic acid, lactic acid, citric acid and butanol are already made via fermentation processes on a commercial scale and can be used in a wide range of markets such as fuels, nutraceuticals, personal care and cosmetic ingredients. These materials often need to compete against petrochemical derived equivalents. The market size for, and the price of, these products is given in Table 5 below.

62 Chemicals – The UK advantage. Adding value for global investors and industry. UK Trade and Investment.
63 http://www.nnfcc.co.uk/tools/biochemical-opportunities-in-the-uk-nnfcc-08-008/at_download/file

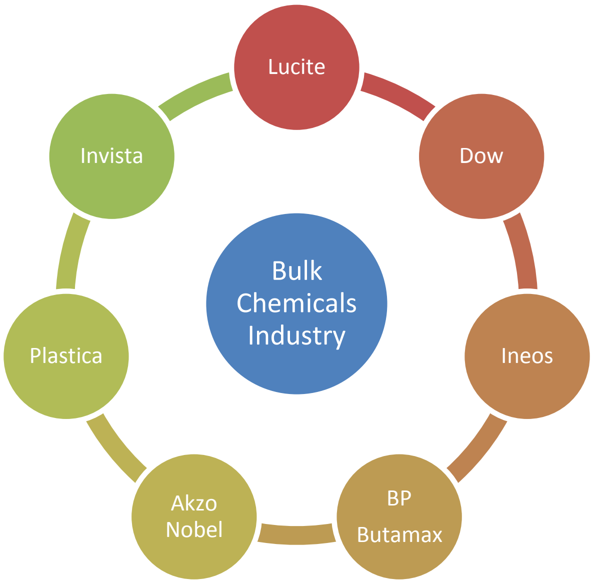


Figure 21 - Key players in the UK Bulk Chemicals Industry

By 2020, the European bio-based plastics market is expected to be 1 million tonnes with a total market value of £1 billion. The global market size and market price for a number of biobased chemicals is given in Table 5 below.

Table 5- Market Size for Bulk Chemicals Derived from Fermentation

Product	Market Size	Market Price
Ethanol	61,000,000 tonnes (2010)	£600-690 (2010)
Butanol	3,000,000 tonnes (2011)	£1,100 tonne (2010)
Lactic Acid	>300,000 tonnes (2010)	£800-950 tonne (2011)
Succinic Acid	~30,000 tonnes (2011)	£ 2,000-£3,000 (2010)
Polyhydroxyalkanoates	<1,000 tonnes (2009)	£1,200 – 4,000 (2010)

Of the chemicals mentioned above, it is likely that succinic acid and polyhydroxyalkanoates markets will expand in future years with the development of low cost biological manufacturing routes.

5.3.2 Speciality Ingredients

There are over 550 consumer chemicals companies operating in the UK employing 34,000 people. Producing soaps, detergents, cosmetics and personal care products, these companies generate £5.8 billion of turnover. Recognisable consumer chemicals companies in the UK include Unilever and PZ Cussons. The consumer chemicals sector is particularly strong in the Yorkshire area of the UK where a Personal Care cluster has been developed by the regional chemical cluster Yorkshire Chemical Focus. Over 1,300 speciality chemical companies are active in the UK employing 63,000 people and generating £11 billion of turnover. These companies produce a wide range of products including dyes, paints, adhesives and fragrances. World leading speciality chemical companies based in the UK include Croda and Johnson Matthey as shown in Figure 22.

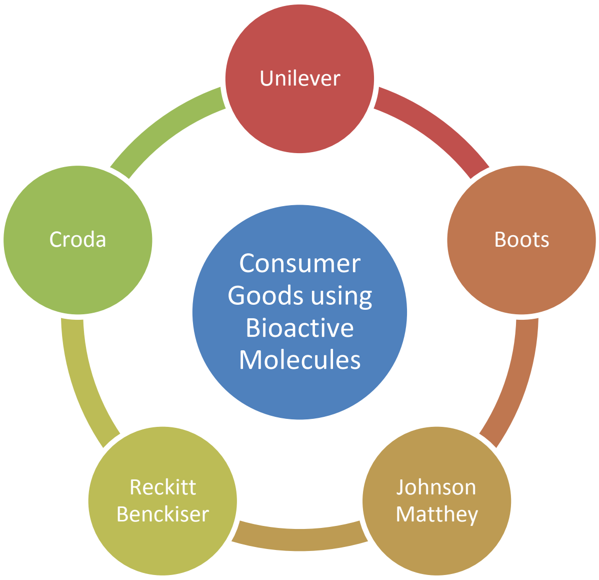


Figure 22 - Key Players in the UK Consumer Goods Industry

Speciality products cover a wide range of products and application areas including cosmetics, personal care and food ingredients. Speciality products are sold on the basis of effect during use and their value can vary depending upon application area from around £5 to £1,000 kg with market volumes varying from around 1,000 tonnes to 100,000 tonnes. Speciality ingredients provide one of the key ways of product differentiation on the market; therefore it is difficult to say what chemicals the UK speciality ingredients industry requires as such information is kept a closely guarded secret. Such information would only be disclosed under NDA with specific groups. Therefore, at this stage in networking it is most pertinent to focus on competences and functional properties such as UV absorbents, moisturisers, fragrances and colours rather than specific molecules.

Both microalgae and sea fish waste are already used for the production of a wide range of different products which in turn, can be used in a wide range of different applications. Such products may carry a premium over synthetic alternatives, especially where there are tangible performance benefits, for example beta carotene. The UK consumer goods industry may require these ingredients or may be working on novel applications. The market size of a selection of commercially available microalgal products is given in Table 6 below and selected sea fish processing products in Table 7.

Table 6 - Market Size, in Dollars, of Products from Microalgae

Product	Market Size
Carotenoids	$1.07bn (2010)
Astaxanthin	$234 mn (2007)
Astaxanthin and Canthaxanthin	$ 310 mn (2007)
Lutein	$ 105.1 mn (2006)
Beta Carotene	$ 392 mn (2010)
Omega 3 oils	$ 1,286 mn (2008)

Table 7 Market Size, in Tonnes, of Selected Products from Sea fish Processing

Product	Market Size
Chitosan	13,700 tonnes (2010)[64]
Chitin	41,400 tonnes (2012 projection)[65]
Gelatin	326,000 tonnes[66]

For bulk and speciality chemicals, if a target product was identified, a wider group of technology companies could be engaged, for example, Novacta and Ingenza, who are contract research organisations.

64 http://www.nutraceuticalsworld.com/contents/view/30300

65 http://www.prweb.com/releases/chitosan/chitin/prweb848574.htm

66 Recent Advances Pave Way for Fish Gelatin For Food (2009) Aquapreneur. http://www.aquapreneur.com/2009/05/11/recent-advances-pave-way-for-fish-gelatin-for-food/

6 Relationship and Network Evolution

Bilateral cooperation between the UK and Norway can help promote knowledge exchange, build partnerships for mutual benefit and provide the impetus for longer lasting collaboration in areas as being strategically important. Collaboration between UK and Norwegian parties could be developed through actions ranging from general opportunity awareness, to specific interactions between companies through to facilitating collaboration in joint activities either targeted at European FP7 calls or specific bilateral funding calls.

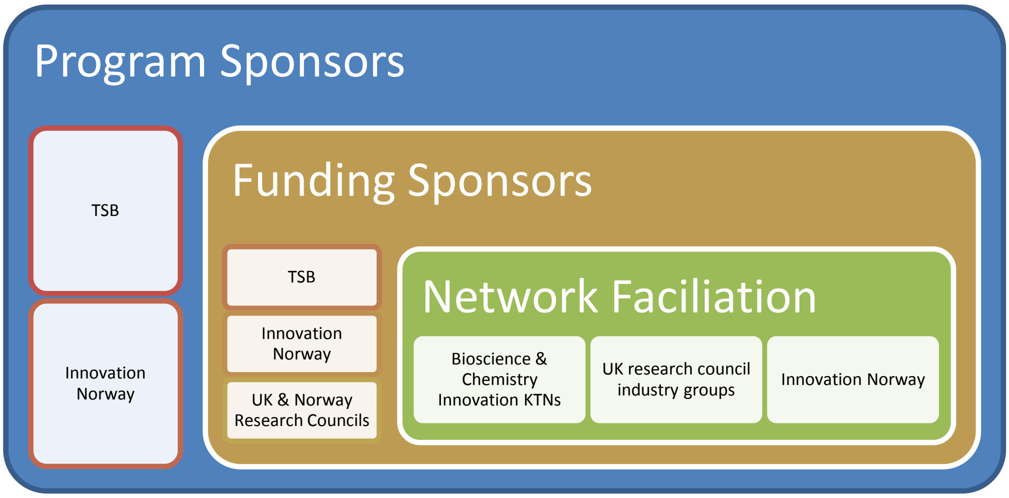


Figure 23- Developing links between the UK and Norway

The building of a bilateral relationship will require three levels of activity as shown in Figure 23. In the first instance the programme requires leadership. Innovation Norway and the TSB have initiated the programme and it is important that the two parties continue to drive the collaboration. Secondly, in order to developing the collaboration, funding will be required to:

1. Bring groups together for knowledge exchange and consortia building
2. Enable research and development projects to take place.

While TSB and Innovation Norway can play a lead role in this funding, the Research Councils in both Norway and the UK should be consulted on how they could participate in the collaboration. The final level of activity is the facilitation of networking and relationship development. Each of these factors is further explored in the following sections.

6.1 Research funding

Funding for joint UK Norway research projects could be accessed through a number of routes. The nature of the preferred funding route should influence the nature and timing of future workshops. The TSB and Innovation Norway are both research funders and therefore have the ability to directly develop funding calls and determine both scope and timings for calls. The research councils could also be instrumental in funding research. However discussion with the research councils would be required to determine the possible interest in bilateral agreements[67]. European programmes could be a source of funds and a mechanism for collaboration.

Pre-emptive networking and relationship building could result in UK and Norwegian researchers collaborating in framework programme projects or in European Research Area Networks (ERA-net) projects. Three research areas of particular relevance to this study are Industrial Biotechnology (ERA-IB), Marine Biotechnology and Wood Wisdom. Neither party is a member of the Marine Biotechnology ERA-Net. The Research Council of Norway is a member of Wood Wisdom and an observer of the ERA-IB. The TSB is a member of the ERA-IB. It is suggested that both parties consider participation in the Marine Biotechnology ERA-Net, that Norway reviews changing it status in ERA-IB from observer to full partner and that the UK reviews changing its status in Wood Wisdom from a joint call funding organisation to a full partner. Programme partners within the ERA-Net programme should ensure that they are aligned with the goals of collaboration between the UK and Norway.

6.2 Network facilitation

In comparison to the UK the size of the Norwegian research and industry base is relatively small. This should allow efficient networking to place through the coordination of Innovation Norway. Due to the amount of research performed in the UK and large number of target companies it would be difficult for one organisation to effectively facilitate the necessary networking. Fortunately the UK has a number of stakeholder groups actively working in the area of biorefining and biotechnology. These groups could be used to raise awareness of the opportunities for bilateral collaboration and used as a conduit for making further connections to UK academic groups and UK companies.

The UK's Knowledge Transfer Networks (KTNs)[68] play a fundamental role in linking academia with industry and facilitating the uptake of academic research by commercial companies. In the space of biorefining and biotechnology the key KTNs are the Biosciences KTN and Chemistry Innovation KTN[69]. The Biosciences KTN serves the agriculture, food and industrial bioscience sectors and would be the primary conduit to engage with the UK's industrial biotechnology companies. The Chemistry Innovation KTN serves the UK chemical producers and the UK's chemical using industries. The Chemistry Innovation KTN would be the primary conduit to engage with companies looking for opportunities to incorporate bio-based materials into their product ranges.

In collaboration areas aimed at producing ingredients for personal care products, the Yorkshire Chemical Focus Personal Care Programme (PCP) can provide access to a range of companies[70]. The PCP facilitates the formation of partnerships that enhance the profitability and competitiveness of members of the personal care supply chain. The programme has a focus on the concentration of companies in Yorkshire and the Humber regions of the UK, but, in the spirit of open innovation, have an extensive network of contacts with companies and partners across the UK and beyond. Likewise, for access to bulk chemical markets, there are a number of regional bodies to facilitate networking.

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67 Discussion with the BBSRC indicated that they prefer to work bilaterally with non-European states and regard European interaction as being served by existing programmes e.g. framework programmes and ERA-Nets

68 https://ktn.innovateuk.org/web/guest/home

69 https://ktn.innovateuk.org/web/biosciencesktn, https://ktn.innovateuk.org/web/chemistryinnovationktn

70 http://www.ycf.org.uk/PersonalCareProgramme/

These are NEPIC in the North East, Chemicals North West in the North West and Humber Chemical Focus on Humberside.

The UK's research councils operate a number of stakeholder groups working in the area of biorefining and biotechnology. These groups could serve as platform for networking and competency sharing with Norwegian interests. Some of the principal networking groups in this area are explained in more detail below.

BBSRC Sustainable Bioenergy Centre (BSBEC)

Established in January 2009, the BBSRC Sustainable Bioenergy Centre considers the major areas of biological research underpinning the development of the bioenergy pipeline, from biomass crop improvement production to bio processing, and covering the social, economic and legal implications of bioenergy production and utilisation. The Centre brings together 12 universities and research institutes and 14 industrial partners and has an initial budget of £ 27 M over the first five years. In total, 4 research themes have been supported -

- Ensuring sustainability
- Widening the range of starting materials for bioenergy
- Making plant cell walls easier to break down
- Optimising fermentation to produce fuel

SUPERGEN

The SUPERGEN (Sustainable Power Generation and Supply) programme was set up by the Engineering and Physical Sciences Research Council (EPSRC) in partnership with the BBSRC, Economic and Social Research Council, NERC and the Carbon Trust. SUPERGEN Bioenergy was managed by Aston University and aimed to develop the complete bioenergy chain, from biomass production through conversion to utilisation of bioenergy products. So far, the SUPERGEN Bioenergy programme has covered two phases. Phase I gained an appreciation of the interfaces between biomass, its cultivation and the impact on thermal conversion processes and products. Phase II of this consortium included the potential of marine biomass, transport fuels and biorefineries. The marine biomass project under the SUPERGEN project was a £80k project which finished in 2011 and included research into the hydrolysis and gasification of macroalgae and macroalgae cultivation.

Algal Bioenergy Special Interest Group

The Algal Bioenergy Special Interest Group is an initiative of the NERC and the Technology Strategy Board which aims to understand the opportunities and risks to the quality of aquatic and marine environments of using macro and micro algal biomass as a source of renewable energy and chemicals. It will bring together a group which will identify the best algal feedstocks for the UK, the most appropriate locations and environmental implications of macroalgal production, and develop predictive modelling tools to assess the implications of scaling up microalgae production. The network will help develop a sustainability framework, analogous to that developed for terrestrial systems.

BBSRC's Integrated Biorefining Research and Technology (IBTI) Club

The IBTI club is a 5-year partnership between BBSRC, the Engineering and Physical Sciences Research Council, and a consortium of leading UK companies[71]. IBTI provides a mechanism to combine the UK's academic expertise in the biosciences with leading companies in the biorefining sector to ensure knowledge transfer and to facilitate a competitive UK economy. The club will invest £6 million to develop biological processes and feedstocks to reduce our current dependence on fossil fuels as a source of chemicals, materials and fuel. Research projects must be industrially relevant, innovative, high quality biological research in biorefining technologies in UK universities and research institutes. The club has three primary themes. These are:

1. Optimisation of feedstock composition.
2. Integrative bio-processing.
3. Enhancing product value.

[71] These are TMO Renewables and Biocaldol, UK ethanol technology developers, Green Biologics, A UK butanol technology developer, Syngenta, a global plant science company, InCrops, a UK non for profit partnership company, HGCA, the cereals and oilseeds division of the UK's Agriculture and Horticulture Development Board, Croda, a global natural products based speciality chemicals company, BP, a global oil company, KWS, a global seed company and British Sugar. More detail on each of these companies capabilities and interests is in Appendix 8.

7 Conclusions and Next Steps

Conclusions

This work has identified four key opportunities where the UK and Norway could develop a strategic working relationship. These opportunities fall into those opportunities which could be exploited by industry in the short to medium term and those which could be exploited in the longer term after a period of sustained R&D and scale up activity.

The short term opportunities are:

1. Using microalgae for omega oils for the aquaculture industry and as bioactive ingredients for the consumer goods industries. The industry has recently enjoyed increased visibility. Further research and development into the identification of novel compounds for specific applications and to reduce the costs of current production opportunities such as omega oils could help further develop this sector.

2. Using marine wastes as a source of bioactive molecules. This is an embryonic industry in both the UK and Norway, but is strategically important given that both the UK and Norway produce considerable amounts of marine wastes. Stimulating activity in this area would require a number of strategic workshops to further develop opportunities and to understand the requirement for underpinning science.

3. Using wood as a feedstock for the production of bulk chemicals and fuels. There has been a concerted effort in the past 10 years to develop effective mechanisms for biomass breakdown and fermentation of lignocellulosic materials such as wood. Commercial implementation of lignocellulosic technologies is beginning in the USA for the production of bioethanol, but nevertheless, there are considerable opportunities for UK and Norwegian researchers to work together to develop microorganisms capable of producing a wider range of chemicals using fermentation, or with increased efficiency compared to those currently available. This is an area where industrial players from both countries could be brought together to assess opportunities for industrial collaboration i.e. Norwegian forest industries collaborating with UK IB companies and to identify gaps in research and knowledge across the supply chain.

In the longer term, a number of projects could be envisaged. Initially these opportunities would need research funding to develop. These include:

4. The utilisation of lignin from the pulping industry as a feedstock for high value chemicals production. While there is currently an industry based on the isolation of lignin products from pulping operations, these products are typically used in markets where the form and not the quality are important. A wide range of higher value products could be made from lignin[72] and this could add value to pulping operations, but there needs to be a concerted and focussed R&D effort in order to make this a reality. This is an area where the UK

[72] For examples see the NNFCC Lignin Factsheet at http://www.nnfcc.co.uk/publications/nnfcc-renewable-chemicals-factsheet-lignin/at_download/file

research base could assist the Norwegian pulping industry develop new products streams. These products could be used by the UK chemical using industries in a wide range of applications.

5. The production of chemicals and fuels from macroalgae. While this opportunity offers a potential significant opportunity for both the UK and Norway given the extensive coastlines of both countries, there needs to be a concerted effort, building upon existing efforts to establish areas and methods for the sustainable cultivation of macroalgae at scale and identify suitable microorganisms for converting the sugars within the macroalgae to chemicals. In this opportunity UK industrial biotechnology developers could work with the Norwegian macroalgae industry and UK and Norwegian research centres to demonstrate the feasibility of this opportunity.

Next Steps

The opportunities and focus areas introduced in this report are the starting point for a more detailed investigation of innovation needs and opportunities and the underpinning research required to realise these opportunities. A number of steps can be envisaged as necessary to realise these opportunities:

1. Mobilizing people and resources
2. Developing a vision of long-term collaboration
3. Obtaining involvement from diverse and non-traditional partners
4. Ensuring support of sponsor organisations (network and funding)

A series of workshops and exchange visits will be required to build relationships and to develop detailed proposals for research and development projects. The objectives of these workshops should be to:

- Provide an open forum for academic and industrial communities to engage
- Assess the perceived barriers and drivers to the adoption of technologies
- Analyse the needs of industry in terms of academic partnerships
- Identify synergies and complementary differences between institutes and industry stakeholders
- Discuss open funding routes to promote cross-border collaboration

Recommendations

In this report, we have shown that there a number of opportunities where joint working between the UK and Norway would be beneficial. However, it is also clear that there needs to be a concerted effort to ensure maximum benefits are obtained from this bilateral relationship. These can be classified as being recommendations broadly related to promoting linkages between the UK and Norway and identification of funding mechanisms.

Promoting Linkages between the UK and Norway

Recommendation 1 - Developing Collaborative Ventures between the UK and Norway in Areas where there are Synergistic Interests and Capabilities.

This report has identified a number of areas where collaboration between the UK and Norway could be beneficial in developing novel bio-based products. Networking meetings will need to be established to bring together partners from both the UK and Norway to discuss the potential for collaborative ventures. The approach needed in these meetings will differ depending upon the target end market.

For speciality chemical applications

The speciality chemical using industries are secretive about products in development preferring to discuss what functionalities are desirable for their product ranges. As a result, we suggest that any meetings should initially focus on the specific competences offered by specific institutes and companies. This will aid the speciality chemicals industry to identify to what extent each of the interested parties could help in the development of specific bioactives of interest and will help more focussed, potentially confidential discussions on opportunities, probably under non disclosure agreements. The Chemistry Innovation KTN is the key contact point in the UK to develop contacts and relationships in the speciality chemicals sector.

a. For the microalgae to high value products opportunity, these meetings should bring together representatives of the biobanks where microalgal strains are held, including University of Bergen, Marine Biological Association, Marbank, NCIMB, CABI and Bergen Marine Biobank and representatives of the UK speciality chemicals using industries including Croda, Boots, Unilever and Reckitt Benckiser, and cluster organisations such as the Yorkshire Personal Care Cluster. This meeting could be organised around the Yorkshire Personal Care Cluster.
b. For the sea fish waste to high value products opportunity, these meetings should bring together representatives of the sea fish processing industry and those involved in the identification of bioactive products from sea fish processing wastes, including the RUBIN foundation, NOFIMA, SINTEF, NOBIOPOL at NTNU, Humber Seafood Institute, University of York, Queens University Belfast, and Glyndwr University, with representatives of the UK speciality chemicals using industry including Croda, Boots, Unilever and Reckitt Benckiser and cluster organisations such as the Yorkshire Personal Care Cluster who could also host the meeting.
c. For the longer term lignin to high value products opportunity, these meetings should bring together representatives of the Norwegian pulping industry, for example Sodra Cell, Norsk Skog, Peterson, Borregaard, UK researchers including University of Manchester and University of Nottingham, and the UK chemical using industries. These meetings could be organised in collaboration with the BBSRC IBTI club which is already funding a number of projects on the potential for using lignin as a feedstock for chemical production.

For bulk chemical applications

In contrast, the chemicals required by the bulk chemicals industry is a better defined area, with specific chemicals of interest for the UK bulk chemicals industry including ethanol, bio-butanol, MMA, lactic acid and succinnic acid.

a. For the wood to bulk chemicals and fuels opportunity, initial discussions would need to discuss how the strengths and strategic interest of the UK industrial biotechnology industry fits with the utilisation of wood residues. These meetings should include representatives from the UK industrial biotechnology providers including Green Biologics, Biocaldol, TMO, Kingston Research Ltd, and relevant university departments including Nottingham University, UMB, Napier University, Imperial College and SINTEF, with the Norwegian forestry industry including Bioforsk, Statskog, Borregaard, PFI, Norwegian Forest and Landscape Institute. This meeting could be organised in conjunction with the BBSRC Sustainable Energy Biocentre.
b. For the macroalgae for bulk chemicals opportunity, as for the wood to bulk chemicals and fuels opportunities, initial discussions between stakeholders would need to assess the alignment of the UK industrial biotechnology industry with utilisation of macroalgae. These meetings should include representatives from the UK industrial biotechnology providers including Green Biologics, Biocaldol, TMO, Kingston Research Ltd and the macroalgae production industry including Statoil, SINTEF, NTNU and Seaweed Energy Solutions from Norway, with SAMS and Plymouth University in the UK.

Recommendation 2 – Promote relationships between complementary enterprises in both countries.

This report has highlighted a number of areas where there are complementary skills between Norway and the UK. These areas underpin the development of the key identified opportunity areas. Collaboration between specific enterprises would not only allow exchange of information between partner institutions but would also aid the development of the opportunities given above.

Collaboration should be facilitated between areas with expertise in:

1. Fermentation. This would promote staff exchanges between SINTEF, IRIS, IFR, NOFIMA in Norway with CPI (NIBF) and Nottingham University in the UK.
2. Macroalgae cultivation. This would promote staff exchanges between NTNU, Seaweed Energy Solutions, Statoil, and SINTEF in Norway with SAMS and the University of Plymouth in the UK
3. Marine biobanks. This would promote staff exchanges between University of Bergen, Bergen Marine Biobank, Marbank in Norway, with CABI, NCIMB and Marine Biological Association in the UK.
4. Biocatalysis. This would promote staff exchanges between UMB Norway, Uni Centre for Applied Biotechnology, SINTEF in Norway, and University of Bath, CoEBio3, Mycologix, University of York and University of Exeter.

There are a number of schemes available through the European Union and national research councils to facilitate the international exchange of academic personnel. As well as exchange of personnel between mutual areas of competence, the collaboration between the UK and Norway should promote wider exchanges, for example between different industries relevant to the opportunities identified in recommendation 1. Wider collaboration between the UK and Norway could be facilitated through the development of a business relationship involving co-marketing, exchange of personnel, and joint management of specific projects.

Recommendation 3 - Mechanisms for the identification of stakeholders in both the UK and Norway needs to be publicised more widely.

The establishment of effective collaboration between the UK and Norway will require stakeholders in both countries to be able to identify stakeholders in the other country with complementary skills, experience and product needs. Innovation Norway is developing a national industrial biotechnology web portal and the Technology Strategy Board has developed a UK- Norway group on its *Connect* site to promote online networking. Integration between the national relevant websites is required. This tool should be well advertised to relevant stakeholders in both countries to ensure that the full value of this resource is realised.

Recommendation 4 – Consideration needs to be given on how to engage with industrial stakeholders.

While all the companies interviewed during the development of this project were interested in the possibilities for collaboration they expressed the need for further information before they would consider allocating staff time or committing to overseas travel. Different levels of engagement may be required for different groups of stakeholders, for example it may be more difficult to encourage industrial partners to engage in networking meetings without prior information exchange on the benefits of engaging with specific companies or academic institutions. In some cases, specific brokerage may be needed to introduce unique capabilities or opportunities for collaboration between complementary stakeholders. Furthermore, careful consideration should be given to the meeting location, the associated costs of participation. In particular, mechanisms for funding specific collaboration activities should be made available prior to meetings so that stakeholders are aware of how activities could be funded.

Funding Collaborative Projects

Recommendation 5 - Upcoming calls in the European Framework Programme and similar schemes such as Interreg should be reviewed and consideration given to the stimulating UK and Norwegian collaboration in appropriate calls.

Given the number of European research funding mechanisms, it may be difficult to engage UK research councils in bilateral agreements with European partners. Therefore, other methods to fund joint activities need to be identified. Given that both the UK and Norway are eligible for European funding, we suggest that Innovation Norway and Technology Strategy Board review upcoming calls for action under the wide variety of European funding schemes and focus networking and consortia building activities around these calls. This could allow access to EU funding streams.

Recommendation 6 - The TSB and Innovation Norway should review their countries participation in ERA-Nets.

The TSB and Innovation Norway should review their countries participation in ERA-Nets aligned to biorefining and industrial biotechnology. The ERA-Net programme could provide an effective mechanism for the funding of collaborative research projects involving UK and Norwegian partners.

Recommendation 7 – Identify and promote alternative funding schemes

We estimate that between four to five projects could be funded for each collaboration area, and, assuming that each programme is made up of 50% public funding and 50% industrial funding, around £2 million funding would be needed for each area.

Given the constraints of existing funding mechanisms for collaborative research projects, a possible route to engage with companies would be through specific TSB and Innovation Norway funding schemes. These may be available to partners in both countries or to partners in one country alone.

One example of funding available to both countries to work on an area of specific interest is the Norwegian IFU contract scheme, where the cost is split equally between a large business partner, a technology developer (typically an SME) and Innovation Norway. This may be a mechanism by which to promote collaboration between companies in both countries with complementary expertise, for example if a UK consumer goods company was interested in using bioactive compounds from Norwegian resources.

Another possible route for funding collaborative ventures, is through funding enterprises in one country alone with match funding identified from the other country for their partners. It may be pertinent for TSB to consider, especially for the high value chemical opportunities, developing a call similar to the 'Manufacturing High Value Chemicals through Industrial Biotechnology' call, with a scope focusing on the identified opportunity areas but not excluding other opportunities. We estimate that for each of the four opportunities identified in this report, around £2 million public funding would be required to support four to five projects based on 50% public funding being matched with 50% industrial funding.

Information on the IFU scheme, and other funding routes for collaboration, should be made available to stakeholders interested in forming a bilateral research agreement.

Appendices

The following section provides more information on several of the areas mentioned in the summary report.

Appendix 1 - MEMORANDUM OF UNDERSTANDING between INNOVATION NORWAY and the TECHNOLOGY STRATEGY BOARD

MEMORANDUM OF UNDERSTANDING

Between

INNOVATION NORWAY

and the

TECHNOLOGY STRATEGY BOARD

1. INTRODUCTION

a. In order to share costs across governments and maximise exploitation of research and development in areas of common interest the above parties have the intention of jointly funding and supporting activities under the auspices of the following Partnership.

b. The purpose of this document is to describe the arrangements for the collaboration between the Innovation Norway (IN) and the Technology Strategy Board (TSB) in the funding and management of the Partnership.

c. The activities of the Partnership are jointly administered by the TSB and IN.

d The Partnership will support a number of activities based on Industrial Biotechnology and Biorefining. Both parties believe that these technologies underpin the bioeconomy, which in Europe has a market size of €2 trillion and employs 21.5 million people. Investment in these technologies can help to meet the increasing demand for a *sustainable* supply of food, industrial products and fuels. Both organisations believe that through joint activities such as knowledge exchange and research and development projects, they will generate economic growth.

2. DEFINITIONS

"IN" means Innovation Norway, whose contact details are set out at paragraph 3 below;

"TSB" means Technology Strategy Board, whose contact details are set out at paragraph 3 below;

"MOU" means this memorandum of understanding;

"Partnership" means the plan of shared activities defined in Appendix 1;

"**Industrial Biotechnology**" is the use of biobased feedstocks and biotechnologies, such as biocatalysis, to develop new, more efficient and sustainable methods to produce energy, chemicals and materials.

"**Biorefining**" is the identification, extraction and modification of valuable components from a biobased feedstock.

3. PARTNER DETAILS

a. Innovation Norway is a government owned and financed organization offering advisory services and financial support in order to nurture business innovation and entrepreneurship, foster regional development, international cooperation and market access. Innovation Norway acts as an advisor to the Government on industry policy in close cooperation with the Norwegian Research Council. It is a main priority for Innovation Norway to help Norwegian companies become leaders in the utility of renewable resources, e.g. efficient value creation from wood or marine derived biomass, areas where Norway by tradition is strong.

b. The Technology Strategy Board's role is to stimulate technology-enabled innovation in the areas which offer the greatest scope for boosting UK growth and productivity. We promote, support and invest in technology research, development and commercialisation. We spread knowledge, bringing people together to solve problems or make new advances. The UK has strong capabilities in bioscience through a combination of world-class academic research and a vibrant mix of small and medium-sized companies, particularly with an industrial biotechnology expertise. The Technology Strategy Board believes that we can support the UK to realise its potential to become world leader in this area - at the heart of the most dynamic region in the developing bio-based economy.

c. Contact Details

Party Name	Technology Strategy Board	Party Name	Innovation Norway
Name	Merlin Goldman	Name	Ole Jørgen Marvik
Title	Lead Technologist	Title	Sector Head, Health and Life Sciences
Address	A1, North Star House	Address L1	Innovasjon Norge
Address	North Star Avenue	Address L2	P.O. Box 448 Sentrum
Address	Swindon	Address L3	(Akersgata 13)
Address	UK	Address L4	0104 Oslo
Address	SN2 1UE	Address L5	Norway
Tel:	+44 1793 442700	Tel:	+47 22 00 25 00
Email:	merlin.goldman@tsb.gov.uk	Email:	olmar@innovationnorway.no

d. Other organisations may choose to support or fund elements of the Partnership. If this happens, their additional contributions and requirements may be documented as an Appendix.

4. DURATION

It is planned that this MOU will be in place for the duration of the Partnership. The proposed duration of the Partnership is 3 years plus an additional 2 years to complete and evaluate ongoing projects. However, this is an estimate only and is subject to alteration by the IN and TSB at any time. Partnership activities will be planned and budgeted on a yearly basis.

5. PROJECT APPLICATION, ASSESSMENT AND MONITORING

a. A joint project application, assessment and monitoring process will be designed, based on existing methods where possible. Organisations that receive funding from the Partnership for research projects will be funded by their own relevant national funding organisation. Decisions on the appropriateness of settling claims rest with the relevant organisation. Also if there are any non-routine matters to be dealt with, such as any concerns related to Project progress, issues requiring resolution, or if there is any doubt as to the appropriateness of settlement of any particular claim or set of claims, then these will be discussed in reviews to be arranged by IN and the TSB.

b. The application and monitoring process may be added as an Appendix when completed.

6. USE AND EXPLOITATION OF INTELLECTUAL PROPERTY

a. IN and TSB agree not to cause or permit to be done anything which may damage or endanger the intellectual property of the project participant's title to such intellectual property, or assist or allow others to do so.

b. The use of all intellectual property rights is to be determined by the project participant which owns those rights.

7. FINANCIAL ARRANGEMENTS

a. As a general principle, TSB and IN will support the activities of project participants from their respective countries, i.e. TSB will support UK driven research and IN Norwegian driven research as further described in Appendix 1. Exceptions to this rule and Appendix 1 will be mutually agreed on a case-by-case basis.

b. IN's contribution to the funding for each activity is expected to be in line with standard Innovation Norway policy and criteria.

c. TSB's contribution to the funding for each activity is expected to be in line with standard Technology Strategy Board policy and criteria.

d. For any jointly funded activities the balance due to one party will be settled by invoicing the other party in arrears.

8. CONTRACTING AND RISK

a. The joint IN and TSB grant support for co-funded Projects will be awarded through TSB and IN grant offer letters which are legally binding. Any special monitoring or reporting requirements should be included in the offer letters.

b. IN and TSB are only responsible for their own part of co-funded projects according to the respective grant offer letter.

9. CONFIDENTIALITY

a. Except as permitted by this paragraph, IN and TSB agree not to make or permit any disclosure of the existence or the terms of or any negotiations related to grant applications.

b. Disclosure about grant applications is permitted to the extent that it is required by law or the general policies of the funding parties, e.g. the disclosure of the names of successful applicants.

c. Announcements, grant calls and press releases about the partnership should be mutually agreed by written approval. Permission to publicise the partnership in general should not be unreasonably withheld or delayed.

d.

Authorised signatory on behalf of the Technology Strategy Board	Authorised signatory on behalf of Innovation Norway
Signature: Name:	Signature: Name:
Position in Organisation	Position in Organisation
Address Technology Strategy Board North star House North star Avenue Swindon Wiltshire SN2 1UE	Address Innovasjon Norge Akersgata 13, 0104 Oslo Norway
Date:	Date:

Appendix 1 – Proposed Activities

Consultancy – Identifying Opportunities

Tender and manage the completion of a report on the high level opportunities and synergies for Norway and the UK. A follow up report focusing on more specific market or technology areas may be commissioned on completion of the initial study.

Split of cost: 50:50
Budget: £15,000 total to be spent in 2011. The UK portion will be supplied by the Biosciences KTN (a networking organisation funded by the Technology Strategy Board). Further work, i.e. beyond 2011, will be considered and mutually agreed between the Partners if required to build on the work completed.
Description of activities: The tender document for the first joint work is included in Appendix 2.

Online Networking

Innovation Norway intends to build a national Industrial Biotechnology web portal. Technology Strategy Board will generate a UK-Norway group on its *Connect* site to promote online networking. One could envision building a system for functional integration between the national relevant web sites, and this integration may involve some cost.

Split of cost: 50:50
Budget: as required per partner, management time will be required on both sides.
Description of activities: A technical solution to cross reference/synchronize information and contact databases. This could be built around a dedicated page for the UK-Norway collaboration on the respective national websites. The respective organisations will maintain their own sites unless a single jointly managed solution is created.

Physical Networking

In order to identify and encourage collaborative projects, the partners will organise networking events in both the UK and Norway. These events could be study trips, seminars, matchmaking or could also focus on knowledge transfer within a specific topic or opportunities for venture capital. They might also be aligned to other events e.g. conferences or site visits.

Split of cost: host country to cover meeting costs in their own country e.g. venue, food, management time.
Budget: A total of £10,000 annually for each party, management time will be required on both sides.
Description of activities: 2-4 events per year, on average distributed equally between the countries.

Pilot and Demonstration Facilities

Industrial biotechnology and biorefining projects often require access to pilot or demonstration facilities and expertise on process development and scaling-up. The UK and Norway has a number of centres of excellence that provide these capabilities. These facilities will be highlighted to stakeholders in both countries, through presentations or study tours.

If such facilities identify areas of cross-border complementarity , for instance if one UK facility focuses on fermentation technologies, while a Norwegian facility focuses on separation technologies, the facilities may wish to form a business relationship involving co-marketing, exchange of personnel and joint management of specific projects. Exchange of technical personnel to encourage knowledge transfer and technical interaction might be supported.

Split of cost: 50:50 in terms of management time involved in organising such visits and study tours. Contributions to travel and associated costs may be available on a case-by-case basis.
Budget: £50,000/year
Description of activities: Agree on site visits, organise trips and promote.

Norway-UK collaborative R&D projects

Projects may include companies, research and technology organisations and academic research groups, funded through a competitive process. Projects could be at any stage along the technology or product development chain. Whether projects involving only academia will be funded will depend on the participation of the respective Research Councils.

The general principle is that all grants should be based on predefined policy and quality criteria. Moreover, each country would only be obliged to fund their own organisations (i.e. their part of the budget of successful projects). Each call for grant applications will have its own requirements e.g. topic, timing, minimum size of project, assessment criteria or a minimum level of bilateralism.

Examples of potential topics:

a. Feasibility projects where marine or terrestrial feedstocks are used to create high value products and biofuel

b. Development of novel technologies for biocatalytic conversion

c. Pilot scale demonstration of novel processes

Split of cost: depends on the make-up of individual projects and their requested grant funding
Budget frame: an indicative £5million for the term of the agreement, expected to fund 5-15 projects
Description of activities: Agree on topics, organise calls, evaluate applications, monitor and administrate grant scheme.

An alternative funding scheme would follow the Norwegian IFU contracts, where cost is split equally between a larger business partner (a so called “demanding customer”), a technology developer (typically an SME) and Innovation Norway. This scheme would be suitable for projects involving a UK large chemical company and a Norwegian SME developing a relevant process.

Knowledge Transfer Partnerships is Europe's leading programme helping businesses to improve their competitiveness and productivity through the better use of knowledge, technology and skills that reside within the UK knowledge base. It might be possible for UK companies to accept graduates from Norwegian universities or vice versa.

European Projects

The Parties have the intention to monitor EU calls for funding and encourage consortia containing UK and Norwegian partners to bid into the calls assisted by the activities 1-3 above. For instance, the ERANET in Industrial Biotechnology or the CSA action on Marine Biotechnology.

Appendix 2 – List of Working Hypothesis

Hypothesis 1 - New opportunities for the UK's personal care sector can be realised through engagement with Norway's marine bioprospecting community.

Rationale – The marine bioprospecting industry is established in Norway and benefits from significant infrastructure support. The UK has an exceptionally strong personal care industry which is innovative and constantly looking for new ingredients to provide product differentiation.

Hypothesis 2 - A beneficial relationship can be developed between Norway's marine bioprospecting industry and UK biotechnology companies.

Rationale – Norway's active marine bioprospecting programme will provide leads for development biotechnology tools by UK research groups and IB companies.

Hypothesis 3 - The UK's research expertise in the biological manipulation of lignocellulosic biomass can be utilised by Norway's forest industry.

Rationale – Due to changes in the paper market the forest industry is under pressure to diversify its product range. In order to effect this change new technologies for the processing of wood are required.

Hypothesis 4 - The UK's research expertise in the thermochemical processing of biomass can be utilised by Norway's forest industry.

Rationale – The pulping industry produces biomass containing side streams which are multi-component and difficult to process using biological methods. Thermochemical processing of these side streams can be used to produce bio-oil or synthesis gas which can then be processed to value added products.

Hypothesis 5 - The UK's research expertise in Green Chemistry for processing biomass can be utilised by Norway's marine and forest industry.

Rationale – The UK has a number of centres working on Green Chemistry and bio-based products. This expertise could be leveraged to help derive value from Norway's abundant biomass resources.

Hypothesis 6 - The UK's industrial biotechnology industry can provide tools and processes for the UK and Norway marine products industry.

Rationale – Both Norway and the UK have large marine products industries generating significant quantities of by-products. Industrial biotechnology could be a means to add value to these by-products.

Hypothesis 7 - New algal technologies can be jointly developed to exploit sources of heat and carbon dioxide.

Rationale – heat and CO_2 are traditionally seen as waste products from other industries such as cement manufacture, power generation and distilling. Value can be added to these waste streams by using them as a feedstock for algae production and using the algae as a source of bio products or bioenergy.

Hypothesis 8 - A relationship can be developed between the UK chemical and chemical using industry and Norwegian raw material processers.

Rationale – The chemical sector is one of the UK's most successful manufacturing industries, it has sales of £60 billion per year and contributes a £6.5 billion surplus to the UK trade balance. The UK is a significant importer of chemicals which it converts to higher value materials for sale in the UK or export. The Norwegian forest industry could be an exporter of bio-based chemicals to the UK.

Hypothesis 9 - The UK and Norway could work collaboratively on the development of novel systems for Anaerobic Digestion of diary and marine by-products.

Rationale – Anaerobic digestion (AD) is an effective method of processing biological waste streams with high moisture content. The UK is developing its capabilities in AD and could undertake joint development projects with Norway.

Hypothesis 10 - The UK and Norway could work collaboratively on the production of macroalgae for energy.

Rationale –Macroalgae can be used through a range of conversion technologies to provide energy. Norway has significant expertise in harvesting macroalgae and processing it to a range of value products, and has expertise in farming of macroalgae in the sea. The UK has some experience in this sector, but could benefit significantly from existing Norwegian expertise.

Appendix 3– Stakeholders present at Norwegian Workshops on Industrial biotechnology and Biorefining

Venue: IRIS, STAVANGER,
WEDNESDAY 13TH APRIL

Company	Name	Role
Innovasjon Norge	Ole Jørgen Marvik	Sector Head, Health and Life Science
Innovasjon Norge	Marit Valseth	Senior Advisor
Innovasjon Norge	Kari Holmefjord Vervik	Senior Advisor
Norwegian Research Council	Audun Øksendal	Senior Advisor, Innovation
IRIS - Stavanger	Arild Johannessen	Department Head, Biotechnology
IRIS - Stavanger	Anne Hjelle	Direktør
Prekubator	Gunnar Kleppe	Senior Advisor, Business Dev.
NORUT	Erling Sandsdalen	Research Director
NOFIMA - Ås	Anders Trømborg	Marketing Manger
Uni Miljø	Hans T. Kleivdal	Senior Researcher
Marine Bioproducts AS	Kjartan Sandnes	Director R&D
Felleskjøpet Rogaland og Agder	Stein Lima	
EWOS	Richard Taylor	

Venue: SINTEF, TRONDHEIM,
THURSDAY 14TH APRIL

Company	Name	Role
Innovasjon Norge	Ole Jørgen Marvik	Sector Head, Health and Life Science
Innovasjon Norge	Bergny Irene Dahl	Head of Bioenergy Program
Innovasjon Norge	Elin Kolsvik	Senior Advisor
SINTEF - Trondheim	Trond Ellingsen	Research Director
SINTEF	Bernd Wittgens	Senior Researcher - Biorefinery
SINTEF	Håvar Slettan	
NOFIMA - Tromsø	Inge Nilsen	Senior Advisor

NTNU	Gudmund Skjåk-Bræk	Senior Scientist - Biopolymer engineering
PFI	Philip André Reme	Research Director
PFI	Ingvild A. Johnsen	Senior Scientist
UMB	Svein Jarle Horn	Scientist (Dr. Ing.)

Appendix 4 – Examples of Norwegian biorefinery research

New, innovative pretreatment of Nordic wood for cost-effective fuel-ethanol production

- The main objective of this project is to develop pretreatment techniques that will reduce the overall production costs for fuel-ethanol from Nordic lignocellulosic biomass. A second objective is to quantify the possibilities to reduce investment and operating costs by co-locating and integrating the ethanol plant with existing industry infrastructure (e.g. pulp mill, oil refinery). A third objective is to join Nordic research resources in the liquid biofuels area.

Scientific Challenges

- Fundamental understanding of the chemical/physical changes that occurs during wood pretreatment.
- Develop predictive pretreatment models.
- Handling of process liquors and by-products

R&D partners

- Paper and Fibre Research Institute (PFI).
- INNVENTIA AB, Sweden
- SINTEF Materials and Chemistry
- Matis ohf Prokaria, Iceland
- VTT Technical Research Centre of Finland

Cost-effective production of 2nd generation liquid biofuel

- Provide the necessary knowledge platform needed to develop an industrial process for efficient conversion of Scandinavian wood-based raw materials into fuel components.
- Because wood-based ethanol production alone is not economically competitive, the project aimed at developing value-added products from wood lignin and extractives in a biorefinery concept.

Scientific Challenges

- Develop effective pretreatment and separation methods for effective isolation of the chemical components of wood (cellulose, hemicellulose, lignin and extractives)
- Develop processes for effective conversion of the lignin fraction into products suitable for use as transport fuels using existing motor technology.

R&D partners

- University of Bergen
- Royal Institute of Technology (KTH) in Stockholm
- Trøndelag R&D Institute
- Paper and Fibre Research Institute (PFI).

LignoRef - Lignocellulosics as a basis for second generation biofuels and the future biorefinery

- Develop fundamental knowledge about central processes for cost-effective conversion of lignocellulosic materials into second generation biofuels and value-added products

Scientific Challenges

- Central processes include biomass pretreatment, hydrolysis and fermentation of carbohydrates and thermochemical conversion of process by-products

R&D partners

- Norwegian University of Science and Technology (UMB)
- SINTEF Materials and Chemistry
- University of Bergen
- The Norwegian University of Science and Technology (NTNU)
- Paper and Fibre Research Institute (PFI).

Appendix 5 – Examples of UK research supporting biorefinery development

Projects funded through the BBSRC Sustainable Bioenergy Centre
http://www.bsbec.bbsrc.ac.uk/

Contact point: BBSRC Bioenergy Champion, Duncan Eggar (info.bsbec@bbsrc.ac.uk)

Lignocellulosic conversion to bioethanol - The University of Nottingham
http://www.bsbec.bbsrc.ac.uk/programmes/lignocellulosic-conversion-to-bioethanol.html

- To harness the potential of lignocellulosic (plant cell wall) materials for sustainable production of bioethanol, we need to optimise energy output without negative environmental, social or economic impacts. We will optimise the release of sugars from plant cell walls to produce a fermentable feedstock that microorganisms can use to produce fuels and develop robust microbial strains that can use these feedstocks to produce bioethanol.

Aims & Objectives

- We aim to optimise conversion of plant cell wall material to bioethanol by:
- Developing a sustainability tool kit to optimise energy balance and understand environmental, social and economic impacts of processes developed
- Discovering novel fungal enzymes that can deconstruct plant cell walls
- Developing green engineering and chemical approaches to release cell wall sugars
- Developing novel yeast strains and fermentation processes that optimise bioethanol production

Associated Partners

- University of Bath
- Univeristy of Surry
- BP
- Bioethanol Limited
- Briggs of Burton
- British Sugar Limited
- Coors Brewers
- DSM
- Ethanol Technology Limited
- HGCA
- Pursuit Dynamics
- SAB Miller
- Scottish Wiskey Research Institute
- University of Surrey

Perennial bioenergy crops- Rothamsted Research

http://www.bsbec.bbsrc.ac.uk/programmes/perennial-bioenergy-crops.html

- Biomass from fast-growing trees and grasses is a sustainable source of renewable energy. However we need to improve the yields of biomass feedstock to meet government objectives in bioenergy and biofuel. The biggest challenges are to improve yields without increasing inputs and to make more of the plants' carbon available for conversion into biofuels

Aims and objectives

- Improve willow and Miscanthus as sources of sustainable biomass for bioenergy and biofuels
- Optimise sustainable biomass yield by genetic improvement of plants to increase the amount of sunlight captured, the amount of carbon a plant can assimilate over a growing season and the partitioning of the carbon in harvested biomass
- Identify crop variants with improved composition
- Develop tools for selecting genotypes in which more of the carbon in the lignocellulosic (cell wall) component can be captured for bioenergy

Associated programme members

- Institute of Biological, Environmental and Rural Sciences (IBERS)
- Imperial College, London
- University of Cambridge
- Ceres Inc

Cell wall sugars - University of Cambridge

http://www.bsbec.bbsrc.ac.uk/programmes/cell-wall-sugars.html

- We can use enzymes to breakdown plant biomass to release sugars for fermentation. In plants the sugars are locked into the cell walls in ways we currently do not fully understand, preventing effective digestion by enzymes. If we can understand better how the plant sugars are arranged in the cell walls, we can select plants, and match them with the most appropriate enzymes, for more effective biofuel production.

Aims and objectives

- Develop rapid technologies to study the detailof cell wall sugar content in biomass and the enzymes that release sugars
- Improve understanding of the plant genes that control cell wall sugar composition
- Discover enzymes that can release sugars from currently indigestible cell wall components
- Understand how some cell wall sugar structures inhibit effective digestion by enzymes

Associated programme members

- Newcastle University
- Novozymes A/G

Marine wood borer enzyme discovery - The University of York

http://www.bsbec.bbsrc.ac.uk/programmes/marine-wood-borer-enzyme-discovery.html

- Sustainable liquid biofuels can be produced from lignocellulosic biomass such as wood and straw. These materials contain polysaccharides (polymers of sugars) that can be converted into simple sugars which can be fermented to produce liquid biofuels. Currently we lack effective enzymes to digest these woody materials. However, marine wood borers are voracious consumers of lignocellulose and have all the enzymes needed for its digestion.

Aims and objectives

- We have already sequenced the genes that are expressed in the marine wood borer gut and which encode the digestive enzymes. We will study the digestive process in borers and investigate industrial applications for their enzymes in biofuel production.

Associated programme members

- University of Portsmouth
- Syngenta Biomass Traits Group

Second generation, sustainable, bacterial biofuels - The University of Nottingham

http://www.bsbec.bbsrc.ac.uk/programmes/second-generation-sustainable-bacterial-biofuels.html

- Biobutanol is widely recognised as a superior biofuel to ethanol, in terms of energy content, ease of distribution, versatility and applications. However, the strains of bacteria currently used to produce biobutanol generate unwanted by-products and are inefficient. Moreover, they are unable to utilise lignocellulose directly as a feedstock.

Aims and objectives

- We aim to create more environmentally friendly and sustainable processes for second generation biofuel production by:
- Using synthetic biology approaches to generate bacterial strains that can convert lignocellulose to fermentable sugars efficiently to maximise butanol productivity
- Testing the most effective strains on an industrial demonstration scale

Associated programme members

- Newcastle University
- TMO Renewables Ltd

Cell wall lignin - University of Dundee at SCRI

http://www.bsbec.bbsrc.ac.uk/programmes/cell-wall-lignin.html

- Lignin is a strengthening and waterproofing polymer that encrusts the sugar-based polymers in plant cell walls, making them hard to access for biofuel production. Our challenge is to discover how the properties of lignin in barley straw can be changed, to make it easier to produce biofuel (or bioenergy) from this waste material without having any detrimental effects on the yield or quality of the crop.

Aims and objectives

- We aim to help make second generation biofuels both feasible and competitive by:

Identifying the best barley varieties forbioenergy applications and determining how lignin content and structure influence the combustion properties, and the efficiency of biofuel production, of straw

Isolating genes and genetic markers associated with high biofuel yields that will be valuable tools for subsequent breeding of other improved energy crops, such as willow and miscanthus

Associated programme members

- The University of York
- SCRI
- RERAD
- Limagrain UK Ltd
- Syngenta
- AgroParisTec-INRA joint Research Unit of Biological Chemistry
- VIB, Ghent University

Projects funded under the Renewable Materials LINK programme

http://www.nnfcc.co.uk/chemicals-materials/our-services/funding-through-renewable-materials-link-programme

Contact Point – Programme Facilitator, Adrian Higson (a.higson@nnfcc.co.uk)

HOOCH Project - Institute of Food Research (IFR)

http://www.hooch.org.uk/default.htm

- Waste lignocellulosic biomass is produced in abundance throughout the global agri-food chain. Its efficient conversion to biofuel can reduce dependence on fossil resources, increase energy security and reduce competition of energy crops with the food industry.

Aims and objectives

- aims to develop, evaluate and support the commercial exploitation of tailored approaches for converting different sources of agri-food-chain waste lignocellulose into so-called second-generation bioalcohols for the automotive industry.

Associated programme members

- University of East Anglia
- John Innes Centre
- Brunel Univeristy
- ThermoFisher Scientific
- Andams
- Achor
- HGCA
- Vireol
- Wrights Baking
- Biocatalysts
- Lotus Engineering
- Renewables East

Grassohol project - IBERS, Aberystwyth University

- the conversion of high sugar perennial ryegrass to alcohol based transport fuel.

Aims and objectives

- The objective is to develop the technology and provide underpinning science for the utilisation of forage grasses for economically viable fermentation to bioethanol, capable of pilot plant scale-up.

Associated programme members

- Aber Instruments
- Alvan Blanch
- Germinal Holdings
- National Farmers Union
- One51 plc
- TMO Renewables
- Wynnstay Group

Appendix 6 – Existing Mechanisms to support collaboration.

This section aims to review the existing infrastructure to support collaboration in biorefining and industrial biotechnology between the UK and Norway.

The primary UK funders for research projects in biorefining and Industrial biotechnology are

- The Technology Strategy Board
- UK Research councils; Biotechnology and Biological Sciences Research Council (BBSRC), Natural Environment Research Council (NERC), Engineering and Physical Science Research Council (EPSRC)

The primary Norwegian funders for research projects are

- Innovation Norway
- Research Council Norway

A number of mechanisms exist to support international collaborations. These include:

- overseas travel grants[73][74][75]
- support for bilateral workshops[76]
- international collaboration sabbaticals[77]
- Country partnering programs[78]

In general the UK research councils consider that European collaborations should be funded through existing mechanisms such as:

- Framework Programs[79]
- ERA-Nets[80]
- Interreg Programme [81]
- Cost Actions[82]

The website of the Research Council of Norway also emphasises European Collaboration through existing mechanisms[83].

Given the existence of EU funding mechanisms for research support it is important that these mechanisms and reviewed in detail and integrated into the collaboration plan. Basing networking

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73 http://www.epsrc.ac.uk/funding/grants/int/Pages/otgs.aspx
74 http://www.bbsrc.ac.uk/funding/internationalfunding/isis.aspx
75 http://www.forskningsradet.no/en/Researcher_mobility/1193731603755
76 http://www.epsrc.ac.uk/funding/grants/network/Pages/workshops.aspx
77 http://www.epsrc.ac.uk/funding/calls/2011/ics/Pages/default.aspx
78 http://www.bbsrc.ac.uk/science/international/international-index.aspx
79 http://cordis.europa.eu/fp7/home_en.html
80 http://cordis.europa.eu/coordination/era-net.htm
81 http://www.interreg3c.net/sixcms/list.php?page=home_en
82 http://www.cost.esf.org/about_cost
83 http://www.forskningsradet.no/en/EU_Research/1253959711745

around European opportunities would give networking events a focus and maximise the potential for resulting collaborations to access research funding.

The Technology Strategy Board

> "The vision of the Technology Strategy Board is for the UK to be a global leader in innovation and a magnet for innovative businesses, where technology is applied rapidly, effectively and sustainably to create wealth and enhance quality of life"

Iain Gray, Chief Executive

The Technology Strategy Board (TSB) is the UK's national innovation agency. The role of the TSB is to accelerate economic growth by stimulating and supporting business-led innovation. The TSB utilize a number of mechanisms to fulfil this role including:

- Investing in, and funding collaboration and working across business, government and the research community
- Funding R&D in SME's
- Facilitating the exchange of knowledge though networking particularly the UK's knowledge transfer networks (KTN's) and knowledge transfer partnerships (KTP's)
- Supporting a network of elite technology and innovation centres

Bioscience a TSB focus area

The TSB works on 14 focus areas one of which is bioscience. The TSB has a Technology Strategy for the biosciences which runs from 2009-2012. The Strategy indentifies the priority areas for TSB investment. Potential priority areas are assessed against the following criteria:

- The UK has the capability
- There is a large market opportunity
- The idea is ready for exploitation
- The TSB can make a difference

Based on this assessment, the priority areas for bioscience are

- Genomics
- Industrial biotechnology
- Agriculture and food (agrifood)

In developing its strategy the TSB concluded:

The UK has significant capabilities in these [genomics, industrial biotechnology and agrifood] three interlinked areas and has opportunities for further commercial exploitation into large, growing global markets through innovation......

The major applications for these three priority areas include:

- Efficient chemical and biological processes, including catalysis and biocatalysis, and chemical to bioprocesses

- Sustainable energy and materials, e.g. waste treatment and recycling, biofuels, renewables and other biomaterials, and chemicals

In laying out its strategy the TSB has committed to support and encourage and number of endeavours including:

- Greater use of genomics-based technologies and knowledge sharing by UK companies in particular those working in non-competitive , distinct sectors
- Technologies that enable advanced generation biofuels
- Next generation biorefinery technologies

Market Applications

Biofuels and bio-based chemicals

Genomic Technologies

- By sequencing the genomes of novel microganisms, new biochemical pathways can be identified that may be beneficial for the production of biofuel or bio-based chemicals.
- By sequencing the genomes of plants, researches can identify the biochemical pathways that produce biomass and subsequent tailor these pathways for the production of biofuel or bio-based chemicals.

Industrial biotechnologies

- Metabolic flux analysis and system-wide mathematical/statistical tools can identify potential genetic and metabolic targets limiting efficient sugar metabolism
- A wide range of enzymes are required for the processing of biomass prior to fermentation cellulases, amylases, xylanases, laccase, etc

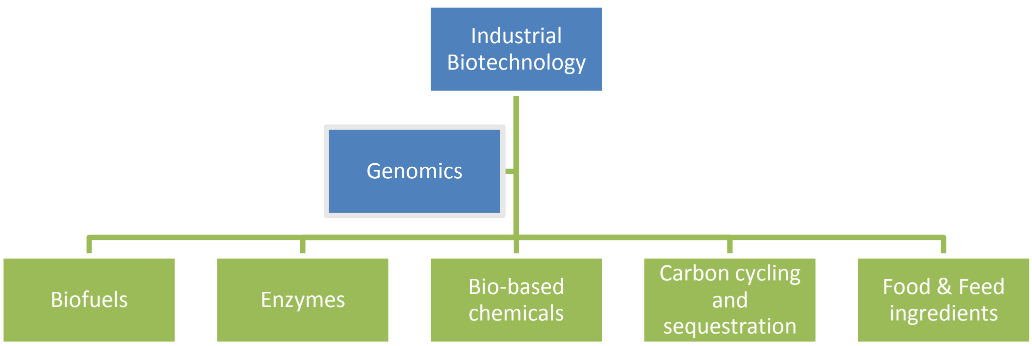

Figure 24 – The Technology Strategy Board Priority Areas of Industrial Biotechnology and Genomics Have Overlapping Market Applications.

Market Applications of industrial biotechnology and genomic technologies (Source Technology Strategy Board)

UK Biotechnology and Biological Sciences Research Council

> We cannot achieve our vision for UK bioscience alone. BBSRC will work with a wide range of partners – nationally and internationally – to co-fund research and training, enhance our understanding of users' needs and deliver a full range of impacts.

BBSRC Strategic plan

Biotechnology and Biological Sciences Research Council (BBSRC) is the UK's principal public sector sponsor for research and training in industrial biotechnology (IB) covering the biological models and the associated biotechnologies for their exploitation.

The BBSRC's strategic plan 2010-2015 lays out it vision for continuing to advance excellent bioscience across the breadth of its remit from molecules to systems. In addition to its commitment to funding curiosity-led research it has identified 3 strategic research priorities.

- Food security
- Bioenergy and industrial biotechnology
- Basic bioscience underpinning health

In February 2011 the BBSRC published it review of support for bioenergy and industrial biotechnology. The review made 11 general recommendations; abridged recommendations of particular relevance for this study are reproduced below:

- *BBSRC should increase the size of its IB portfolio as a proportion of its total budget.*
- *BBSRC should promote IB nationally and* ***internationally*** *through all forms of BBSRC literature and its website to raise the awareness of IB as a strategic priority both within the office [BBSRC] and externally. Promotion of IB should involve working with a range of interested groups including other research councils, knowledge transfer networks, learned societies and trade associations.*
- *BBSRC should seek to identify, develop and promote new and existing mechanisms for working with the private sector which can assist in the translation of the research it supports. BBSRC needs mechanisms for working with companies where the evidence for translation can be clearly demonstrated.*
- *BBSRC should promote collaborative approaches in the area of industrial chemical production from living organisms and should facilitate the bringing together of cross-disciplinary research teams with industry to develop programs of industrially-relevant research.*

The bioenergy and industrial biotechnology review also points out that,

...the UK biocatalysis community is relatively strong but that the BBSRC portfolio is mostly focussed on the needs of the pharmaceutical industry. A major challenge in this area is to build on the current strengths and encourage project involving the production of industrial chemicals from living organisms. This is an area where cross-disciplinary research involving biologists and chemists, as well as integration with the chemicals industry is of particular importance.

The strategic plan is based 3 enabling themes

- Enabling theme 1 - Knowledge exchange, innovation and skills
- Enabling theme 2 - Exploiting new ways of working
- Enabling theme 3 - Partnerships

The BBSRC acknowledges the need to work with many stakeholders and other funders, nationally and internationally, to deliver its vision for UK bioscience. The plan outlines the need to promote the transfer of knowledge and sharing of facilities for the benefit of bioscience.

The BBSRC's international strategy sets out four inter-related areas of activity:

- Promoting the movement of people
- Enabling international research and collaboration
- Ensuring access to world-class infrastructure and information
- Discharging our global responsibilities

Funding Collaboration

BBSRC Partnering Awards

The BBSRC operate a country partnering program which currently includes India, China, Japan and the United States. Due to number of established mechanisms for collaboration between European partners e.g. FP7, COST, ERA-net, the partnering award programme generally, but not restrictively, looks towards non European countries.

The aim of the program is:

- To set up partnership links between UK and overseas laboratories
- To promote the exchange of scientists, particularly early career scientists
- To promote access to facilities

The program typically provides awards of £25-50,000 to enable leading UK laboratories to partner with overseas equivalents. Funds can only be used for travel, subsistence and other activities, such as workshops or exchanges. They are not to fund salary costs, consumables, items of equipment or other research costs, nor to link ongoing single collaborative projects. The BBSRC assess applications against the following criteria:

- The value added to BBSRC science through the partnership by enhancing priority areas
- The benefits and future joint research likely to accrue from the collaboration
- The uniqueness of the opportunity and expertise of partners
- The opportunities for young researcher exchanges
- Whether the collaboration is a new linkage or an ongoing partnership (if collaboration is ongoing, what new aspects are brought to the partnership)
- The level of the contribution made by the UK institution towards the development of the award
- Alignment of the award to current BBSRC strategy priorities

BBSRC International Scientific Interchange Scheme

The BBSRC operates an International Scientific Interchange Scheme (ISIS). The scheme is intended to help scientists add an international dimension to their BBSRC funded research by making and establishing new contacts with international counterparts.

Funding is available for:

- Short Term Travel Award: Normally intended as a first contact-type meeting. Allows researchers to travel outside the UK to initiate collaboration or prepare proposals with partners for international programs (e.g. EU Framework, Human Frontier Science Program)
- Long Term Travel Award: For researchers to travel outside the UK for periods of up to 12 months
- Access Award: For stays of up to one month in another country to undertake a specific piece of work, access facilities not available in the UK or gain access to new techniques or materials, which would be of benefit to the BBSRC project or the UK research team

Funding is limited to travel and subsistence costs only, and does not usually exceed ~£5k.

Appendix 7 - UK and Norway Fermentation Facilities

Facility	Equipment

SINTEF Materials and Chemistry
www.sintef.no
	Laboratory facilities
	• High-throughput screening laboratory
	• Advanced analysis laboratory
	  ○ 3 GC-MS
	  ○ 4LC-MS (singlequadrupole)
	  ○ 1 LC-IonTrap
	  ○ 3 LC-QQQ (triplequadrupole)
	  ○ 1 LC-TOF
	  ○ 1 LC-QTOF
	  ○ 1 GCxGC-QTOF
	• Fermentors 32x3 litres, 3x14 litres
	• Aerobic workstation
	• Membrane filtration and chromatography
	Pilot Plant
	• Fermentors 300 & 1500 litres
	• Centrifuges
	• Cell homogenizer
	• Membrane filtration and chromatography

IRIS, Biosentrum http://www.biosentrum.no/index.htm	Biosentrum specialises in contract fermentation for production, research and development, and process scale-up. Within the plant, biological products can be manufactured on a small scale or in commercial quantities. The largest fermentor has a capacity of 30 cubic metres.

Centre for Process Innovation (CPI), National Industrial Biotechnology Centre
http://www.uk-cpi.com/3_pages/focus/susproc/services/national-industrial-biotechnology-facility/
	NIBF Development Laboratory
	• Cell banking facilities
	• Shake flask capability
	• Innoculation laboratory
	• 1 litre fermentation vessels
	• 10 litre fermentation vessels
	• Downstream processing equipment
	  - centrifugation
	  - homogenisation
	  - cross flow filtration
	  - chromatography
	• Analytical capability
	
	NIBF Pilot Facility
	• Media preparation vessels
	• 15 litre steam in place fermenter vessels
	• 50 litre fermentation vessel
	• 50 litre marine fermentation vessels
	• 750 litre fermentation vessels

	• Downstream processing vessels • Disk stack centrifugation • Homogenisation • Cross flow filtration • Solvent handling and distillation facility • Freeze drying capability • Process analytical technology **NIBF Demonstrator Facility** • Feedstock handling • Feedstock pretreatment - shredder - hammermill - macerator • 5,000 & 10,000 litre upstream dilution and media sterilisation vessels • 1,000 litre small additions vessel and 3,000 litre sterile feed vessel • Continuous media sterilisation • 10,000 litre fermentation vessel - batch or continuous operation - aerobic or anaerobic operation • 10,000 & 4,000 litre downstream process vessels • Below 0^oC to 130^oC temperature control on processing vessels • 2,000 litre glass lined vessel • Centrifugation • Homogenisation • Filter drying • Solvent and distillation capability
University of Nottingham	1000 litre fermentor (operational 2011)

Appendix 8 - IBTI Club Members & Company Information

Biocaldol Ltd

Biocaldol Ltd. specialises in developing turnkey solutions designed to transform the agro-industry. These solutions comprise proprietary, environmentally-friendly micro-organisms, custom-made process design and engineering for the production of second-generation biofuels, animal feed and other biomass-derived products.

Biocaldol's technology is based on proprietary microorganisms and is designed to convert the world's vast and largely under-utilised lignocellulosic biomass resources into renewable motor vehicle biofuel (bioethanol) and other high value industrial chemicals. Short-term, the business is expected to demonstrate cost benefits of at least 50% over current ethanol processes and deliver further cost savings for ethanol producers through the modular and standardised designs.

The current focus of Biocaldol business is system integration. Biocaldol works closely with customers and agro-industrial partners to retrofit conventional ethanol plants, develop process components, provide engineering expertise and gain marketing access within the key market sectors.

Website: www.biocaldol.com

BP Biofuels UK Ltd

BP is of one of the world's largest energy companies, providing its customers with fuel for transportation, energy for heat and light, retail services and petrochemicals products for everyday items. It is the largest oil and gas producer in the U.S. and one of the largest refiners. BP also has a global network of around 22,000 service stations.

BP is a leading player in the global biofuels market. Since 2006, BP has announced investments of more than US$1.5 billion in biofuels research, development and operations, and has announced investments in production facilities in Europe, Brazil and the US. This includes partnerships with other companies to develop the technologies, feedstocks and processes required to produce advanced biofuels, and US$500 million over 10 years in the Energy Biosciences Institute (EBI), at which biotechnologists are investigating applications of biotechnology to energy.

In the UK, BP is furthering its commitment to growing the biofuels market through its joint venture, Vivergo. The joint venture has invested US$400 million in plant which will help meet delivery of approximately one third of the UK's forecast ethanol demand in 2010, required to meet the Renewable Transport Fuel Obligation. Through a separate joint venture, BP is also building a demonstration facility in Hull that will produce biobutanol, an advanced biofuel, which offers a number of advantages and can help accelerate biofuel adoption.

British Sugar Group

British Sugar Group is one of the largest sugar producers in the world; employing more than 42,000 people, operating in 10 countries and producing around 5 million tonnes of sugar each year. Its operations stretch from the UK and Spain in Europe, to southern Africa, to North and South China, encompassing climates suited to both beet and cane, and sited in countries at all stages of economic development.

In recent years, the company has expanding the range of co-products it produces, which now include animal feed, soil conditioning and landscaping products, electricity and even tomatoes. The Group is also involved in the developing bioethanol industry and in seed coating and enhancement technology.

Website: www.britishsugar.co.uk

Croda International Plc

Croda is a world leader in natural based speciality chemicals which are sold to virtually every type of industry. The company has approximately 3,400 employees, working at numerous manufacturing sites, research centres and sales offices around the globe. Our activities can be broadly classified into two sectors: Consumer Care which consists of global businesses in personal care, health care, home care and crop care – all markets with an increasing need for innovation and sustainable ingredients; and Industrial Specialities which comprises base oleochemicals, additives for polymers, polymers and coatings, lubricants and lubricant additives, and processed vegetable oils.

Croda employs a variety of 'traditional' chemical processes to convert natural based raw materials such as woolgrease, vegetable and marine oils, proteins and plants, into a range of speciality ingredients. In addition, however, Croda has developed its own technologies to further refine and derivatise natural products, giving rise to functional actives. With technical centres strategically located worldwide, our technologists work closely together, sharing ideas and information, to ensure that Croda is always at the leading edge of new technology in all its chosen markets.

Website: www.croda.com

Green Biologics Ltd

Green Biologics Limited (GBL) is an industrial bio-technology SME, based near Oxford, pioneering advanced microbial technologies for the conversion of sugars to renewable chemicals and fuels. More specifically, GBL is a world leader in Clostridial ABE (Acetone-Butanol-Ethanol) fermentation and supplies advanced bio- butanol process solutions to large feedstock owners and chemical producers. The company is currently working with a number of feedstock partners in Asia across three continents to pilot and demonstrate its proprietary process.

Website: www.greenbiologics.com

HGCA

Mission: To deliver a world-class arable industry through independence, innovation and investment. HGCA is the cereals and oilseeds division of the Agriculture and Horticulture Development Board (AHDB). It is funded by a statutory levy raised on growers, dealers and processors of cereals and oilseeds. HGCA carries out research and development, market information, supply chain activities and consumer marketing programmes for the benefit of the cereals and oilseeds sector.

Website: www.hgca.com

InCrops

The InCrops Enterprise Hub is a not for profit technology transfer company based in the East of England. The InCrops project has 5 years of funding (2008-2013) from EEDA and the European Union (ERDF) to develop an enterprise hub linking the region's top plant science research with businesses looking to develop new products from biorenewables for the marketplace. We provide business support to regional companies and entrepreneurs developing products and technologies based on alternative and non-food crops. The InCrops project has a strong commitment to low carbon economic growth and promotes sustainable and renewable technologies. We support a spectrum of market sectors including green chemicals, biopolymers, biopharming and high value chemicals. InCrops also has expertise in Life Cycle Analysis. We facilitate development of supply chains, market integration and product innovation. InCrops develops applied and collaborative industry-led projects, develops new products and processes for the exploitation of alternative and non-food crops. Our partners include leading academic institutions in plant science and organisations supporting low carbon and renewable economic growth.

Website: www.incropsproject.co.uk

KWS UK Ltd

KWS UK is a leading provider of agricultural seeds (cereals, oil-seeds, sugar beet and maize) dedicated to providing UK growers with innovative new varieties to meet increasingly demanding end-market needs. It is part of the KWS Group which operates in more than 65 countries, has aturnover of greater than 600million euros and a staff of over 3,000.

KWS is also a leading seed company in the bio-energy area with dedicated breeding programmes for Bio-energy Maize and Sorghum and numerous R&D links with academics across Europe.

Website: www.kws-uk.com

Syngenta Ltd

Syngenta is a world-leading agribusiness. We are committed to sustainable agriculture – farming with future generations in mind. We contribute to that in many ways, for example by raising productivity through innovative research and new technology. Our company provides two main types of products: seeds and crop protection chemicals. Syngenta helps growers around the world increase their productivity and address the world's growing demand for food, feed and fuel and are committed to protecting the environment, promoting health and improving the quality of life. Syngenta was created in 2000. Syngenta is a leader in crop protection, and ranks third in the highvalue commercial seeds market. Sales in 2009 were approximately $11.1 billion. The company employs over 25,000 people in more than 90 countries. The annual spend on R&D is approx $1bn. Our experience with plants goes back many decades. All around the world, our scientists work with a vast range of crops in local conditions, and share their insights globally. Bringing plant potential to life is our company purpose.

Website: www.syngenta.com

TMO Renewables Ltd

TMO Renewables Ltd was founded in 2002. TMO Renewables Ltd has developed a technology which is described as "the sponsor of a paradigm shift in the production of ethanol from biomass". At the core of TMO's offering is an ethanologen, developed in their laboratories. This thermophilic organism operates at high temperatures and digests a wide range of feedstocks very rapidly. TMO has developed a process which exploits these properties to make ethanol from cellulosic biomass in a manner which eliminates the economic barriers that have restricted the development of cellulosic ethanol production.

TMO has built and is currently operating their Process Demonstration Unit (PDU) which is designed to handle a wide variety of feedstocks including wheat straw, corn stover, corn fibre, wood chips, switchgrass, distillers grains etc. It was designed for the upmost flexibility and includes TMO's bespoke design for pretreatment, enzyme hydrolysis and fermentation working in batch or fully continuous mode.

TMO intends to offer this second generation technology in the first instance to the existing corn ethanol sector. By "bolting on" a TMO designed facility at an existing corn ethanol plant, the distillers dried grains and soluble ("DDGs") that arise as a co-product can be further processed into additional ethanol. This will deliver significant energy savings to the plant owner by eliminating much of the DDGs drying requirement: the TMO process requires a wet feedstock. After the cost of corn, drying costs represent the second largest element of the cost of production in corn ethanol. The impact of a twelve to fifteen percent increase in ethanol production from the cellulosic coproduct when combined with the existing starch derived ethanol results in a significant margin increase for the producer.

Website: www.tmo-group.com

Appendix 9 - UK Biotechnology Companies

(a none exhaustive list of UK industrial biotechnology companies)

Applied Enzyme Technology Ltd (http://www.gwent.org/Aet/index.html)

Aquapharm Bio-Discovery Ltd (http://www.aquapharm.co.uk/)

BBI Enzymes (http://www.bbienzymes.com/)

Beocarta (http://www.beocarta.com/)

Biocaldol (http://www.biocaldol.com/)

Biocatalysts Ltd (http://www.biocatalysts.com/)

Biosynergy (Europe) Ltd (http://www.biosynergyeurope.com/)

Biowaste2Energy Ltd (http://www.bw2e.com/)

Envirobac Ltd (http://www.envirobac.co.uk/)

Enzyme Services and Consultancy Ltd (http://www.enzymes.co.uk/)

Glycomar (http://www.glycomar.com/)

Green Biologics (http://www.greenbiologics.com/)

Ingenza Ltd (http://www.ingenza.com/)

Mycologix (http://www.mycologix.co.uk/)

NiTech Solutions Ltd (http://www.nitechsolutions.co.uk/)

Novacta Biosystems Limited (http://www.novactabio.com/)

Nzomics Biocatalysis (http://www.nzomics.com/)

Plaxica (http://www.plaxica.com/)

Recombitex Ltd (http://www.recombitex.com/investment.html)

TMO Renewables (http://www.tmo-group.com/index.aspx)

Appendix 10 - Norwegian Biotechnology Companies

A searchable database of Norwegian Life Science Companies is available at http://www.norbiobase.no/

Axellia Pharmaceuticals (http://www.xellia.com/pages/default.aspx)

Bioprotein (www.iris.no)

Borregaaard Industries (www.borregaard.no)

Calanus (www.calanus.no)

Cambi (www.cambi.no)

Chitinor (www.seagarden.no)

Denomega Nutritional Oils (www.denomega.com)

Marine Bioproducts (www.marinebio.no)

Marine Harvest Ingredients (www.marineharvest.com)

Maritex (www.tine.no)

Probio (www.probio.no)

Scanbio (www.scanbio.no)

Weifa (www.weifa.no)

Weyland (www.weyland.no)

Zymtech Production (www.aminotech.com)