FINAL CLIENT REPORT

CLIENT: **GREENSEAS RESOURCES**

PROJECT TITLE: **MARKET RESEARCH FOR POTENTIAL PRODUCT LINES FOR A NEW SEAWEED FARM**

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1 EXECUTIVE SUMMARY

GreenSeas Resources Ltd (GreenSeas or Client) is a newly established company which intends to become a leading European handler of seaweed, associated products and applications. GreenSeas is currently establishing a site in Wales to set up a seaweed farm, as well as for harvesting of existing stocks.

Aquaculture is the main source of production of marine plants for Africa and Asia, contrarily to America and Europe where production is almost entirely from harvest of wild plants. The majority of marine plants produced globally are red and brown seaweeds (97.4%). Global seaweed production sits at around 30 million tonnes. Asia, and in particular China, dominates the production and purchasing markets and intellectual property landscape for seaweed production and seaweed-derived products.

There has been more interest in seaweed aquaculture in the UK in recent years, mainly driven by research into algal biofuel technologies. However, real-world applications of macroalgae in bioenergy are still several years away. The use of seaweed extracts, such as alginates, are a major application of macroalgae and used extensively across several industries. UK industry is open to using a more local supply of seaweed extracts. However, there is little UK production of such extracts despite demand. One of the reasons for this may be the inability to compete with Asian producers on price, which is a crucial factor for the Client to set up a successful operation.

Within the European seaweed industry, there is currently a lack of a diversified market for seaweeds, but current drives to opening new markets (e.g. sea vegetables, biotech or biofuels) may help push forwards European seaweed production. Importantly, development of the sector should be towards a sustainable seaweed production. This is particularly important for end-user industries of seaweed extracts in Europe, such as packaging and cosmetics, where there is growing demand for natural product-based materials and companies are increasingly eco-conscious.

This report identifies some important European competing organisations to GreenSeas' seaweed farming plans and their business models. However, one important distinction is that most companies do not harvest seaweed and supply seaweed extracts. These steps are typically handled by separate companies, so GreenSeas would be unique in this regard. This may be of benefit to GreenSeas in an industry becoming more eco-conscious, and where GreenSeas initial target customers are ideally smaller, national companies (rather than multinationals).

The seaweed biotech industry appears collaborative – rather than competitive – particularly between geographically relevant organisations (i.e. Europe). Companies across the supply chain (harvesting, processing and extract producers) are open to collaboration/partnering.

Our research and feedback suggests that the two potential longer-term, non-food opportunities for GreenSeas are:

1. To supply dried, processed seaweed at scale to industry users. This is a broad B2B model which allows GreenSeas to target a range of industries, though there are well-established

competitors so the species of seaweed selected by GreenSeas should be based on where there is unmet need in Europe, particularly for smaller companies initially.

2. To supply seaweed extracts to industry users. The company should again focus on Europe as its target market and identify extracts where there is market need but little European supply (such as alginates).

One other avenue not analysed further in this report, but potentially worth exploring as a business model for GreenSeas, is the cooperative approach, a model that has found adoption in the US by an ocean farmer and fisherman-run organisation that uses a sustainable, open-source polyculture vertical farming system, growing a mix of seaweeds and shellfish that require zero input. Crops are used as food, fertilizer, animal feed and more.

2 BACKGROUND

GreenSeas Resources Ltd (GreenSeas or Client) is a newly established company which intends to become a leading European handler of seaweed, associated products and applications. GreenSeas is currently establishing a site in Wales to set up a seaweed farm, as well as for harvesting of existing stocks. The initial uses of the seaweed will be in the food sector - the Client is separately obtaining a market assessment of the potential for the seaweed in the food industry from another provider - and is also developing bioremediation opportunities through environmental nutrient trading and clean-up with internal resources.

However the Client wishes to develop multiple income streams from the seaweed, and would like to understand the potential markets for other uses for the seaweed. They are working with the BEACON project at Aberystwyth on potential biorefining opportunities. The alternative income streams could include:

- biorefining to produce seaweed extracts - traditional products such as alginate or agar, and other high value chemicals that may be identified
- bioenergy – through anaerobic digestion, or biomass for biofuels

The aim of this work is to inform the company's business planning and strategy, as well as to provide evidence to support future fundraising. IP Pragmatics Ltd. (IPP) have been commissioned by GreenSeas to provide:

- An analysis of the business models used by similar seaweed farms
- An overview of the market for each of the potential income streams (biorefining and bioenergy) that have been identified for the company
- Feedback from primary research with companies identified as attractive targets including summaries of the individual interviews
- An initial prioritisation of the potential longer-term, non-food opportunities for GreenSeas

In consultation and agreement with the Client, a decision was taken part way through this project to focus our primary research on the biotechnology/biorefining market.

3 METHODOLOGY

The focus of this market and IP assessment is on the seaweed farming market, and the biotech and bioenergy applications thereof. The report will look at the IP landscape surrounding seaweed farming and processing, the macroalgae market, with particular focus on the biotech and bioenergy segments, relevant players operating in the industry (particularly within UK and Europe) , along with the business models used for similar seaweed farms.

In compiling this report IPP has used the following methods:

- Discussions with the Client to gather background information on their current technical plans and priorities and existing links with potential industrial partners.
- Patent database searches using open source and proprietary patent analysis software from Thomson Innovation.
- Collation of secondary market information from published sources via Internet searches and use of IPP's proprietary market report databases that it subscribes to from sources such as BCC Research, Frost & Sullivan and GlobalData.
- Primary research interviews with key opinion leaders identified from IPP's secondary research

4 INTELLECTUAL PROPERTY LANDSCAPE[1]

IPPL subscribes to Thomson Innovation, a comprehensive patent database and patent landscaping tool that can quickly identify competing or synergistic patents and their assignees as part of an overall IP analysis. Use of this powerful analytical tool is an efficient way to identify both competing and synergistic patents related to a new technology field or application. This tool can also help identify potential licensees and co-development partners.

A series of searches were carried out using the Thomson Innovation database (a subscription database which contains full text patent information from the major patent territories, bibliographic data from other territories, plus augmented data added by Derwent World Patent Index, DWPI).

The following document collections were searched:

Full Text: US Granted; US Applications; European Granted; European Applications; WIPO Applications; British Applications; French Applications; German Granted; German Utility Models; German Applications; Canadian Granted; Canadian Applications

Bibliographic: Japanese Granted; Japanese Utility Models; Japanese Applications; Korean Granted/Examined; Korean Utility Models; Korean Applications; Chinese Applications; Chinese Utility Models; Other Authorities (covered by INPADOC); plus enhanced DWPI data fields

4.1 BROAD PATENT SEARCH

To gain an overview of the seaweed farming/harvesting industry, a broad search was carried out, looking for the following terms in the title, claims or abstract of patents in the included databases:

CTB=((seaweed OR macroalgae) AND (aquaculture OR farm* OR harvest* OR grow*)) AND DP>=(19970828);*

As the emphasis of the patent landscaping was to identify more recent activity, potential freedom to operate issues and information on organisations active in the field, the searching was limited to the past 20 years, i.e. those patents which may still be in force or are yet to be granted.

The search identified 7608 records grouped into 5054 INPADOC patent families. This broad patent set was examined to identify the trends, key companies and organisations involved in related products, countries where the R&D activity originates, etc. More focussed searches were then carried out within this broad landscape in order to identify specific patent activity that relates closely to the Client's areas of interest. These are summarised in later sections.

[1] Detailed patent landscaping was outside of the scope of this project. Further focused searches and analyses can be undertaken e.g. processing methods, assignees of interest

4.1.1 PUBLISHING TRENDS

The following graph shows the patent publishing trends in the broad patent landscape field by year. The steep increase in patenting activity in the last 5 years suggests there is increasing interest and innovation in seaweed farming/harvesting, which reflects similar trends seen in the seaweed extracts and bioenergy markets. The results for 2017 are incomplete, which accounts for the dip at the end of the graph.

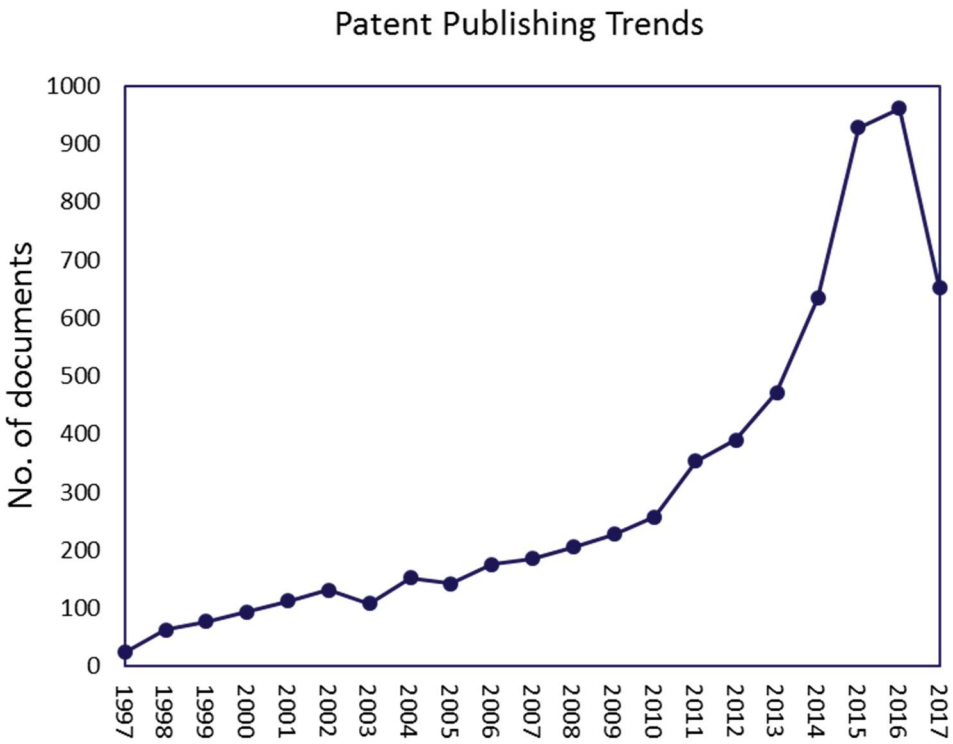

Figure 1: Patent trends for seaweed farming/harvesting

The top 10 most common IPC classifications are shown in the table below.

Current IPC	Document Count	IPC Description
A01K006100	691	A01K – Animal husbandry; care of birds, fishes, insects; fishing; rearing or breeding animals, not otherwise provided for; new breeds of animals 61/00 – Culture of aquatic animals
A01G003300	638	A01G – Horticulture; cultivation of vegetables, flowers, rice, fruit, vines, hops, or seaweed; forestry; watering 33/00- Cultivation of seaweed
A23K000118	519	A23K – Feeding-stuffs specially adapted for animals; methods specially adapted for production thereof 1/18 - Animal feeding-stuffs
C05G000300	491	C05G – Mixtures of one or more fertilisers with materials not having a specific fertilising activity, e.g. pesticides, soil-conditioners, wetting agents 3/00 – Mixtures of one or more fertilisers with materials not having a specifically fertilising activity
A23K000116	423	A23K– As above

Current IPC	Document Count	IPC Description
		1/16 - Addition of microorganisms or extracts thereof, e.g. single-cell proteins, to feeding-stuff compositions
A23K001030	407	A23K– As above 10/30 – rom material of plant origin, e.g. roots, seeds or hay; from material of fungal origin, e.g. mushrooms (obtained by microbiological or biochemical processes, e.g. using yeasts or enzymes
A23K000114	403	A23K– As above 1/14 – Pretreatment of feeding-stuffs with enzymes
A23K005080	286	A23K– As above 50/80 – for aquatic animals, e.g. fish, crustaceans or molluscs
A61K000897	151	A61K – Preparations for medical, dental, or toilet purposes 8/97 – from algae, fungi, lichens or plants; from derivatives thereof
C08H000800	13	C08H – Derivatives of natural macromolecular compounds 8/00 – Macromolecular compounds derived from lignocellulosic materials

4.1.2 KEY ASSIGNEES

The key assignees for the broad patent family search are shown below. The list of key assignees identifies the companies and research organisations most active in the seaweed farming field in terms of the number of separate patent families (covering separate inventions) they own/control.

Unsurprisingly, given the long-standing interest in uses of seaweed and algae in the region, the top assignees are based in Asia. The top assignee is Okabe (Okabe Co Ltd + Okabe KK in the below results), a Japanese construction firm with numerous patents based mostly around the infrastructure of seaweed farming equipment. Zhejiang Ocean University, a public university with specific interests in marine science and other various oceanic disciplines, is the second-top assignee. Other similar companies and universities to Okabe and Zhejiang Ocean University also feature in the top assignees.

One notable finding, however, is that the third-top assignee, Xyleco Inc actually has by far the most individual patent records (2992 in total), having filed for patent protection in a much broader spread of territories (including US, Canada, Japan, China, South Korea, Australia, New Zealand, Europe, Mexico, Brazil) as opposed to much of the other Chinese assignees who have filed mostly just in China. Xyleco Inc is a Biotechnology company focused on "Creating Resources for an Under-Resourced World". The company's headquarters are located in Wakefield, USA. However, they have very little online presence or information available about the company or their activities. All of Xylco's patents[2] have been published in the last few years and most relate to biomass treatment/processing, including seaweed, so this could be one company worth watching in the future.

[2] Key inventor: Marshall Medoff

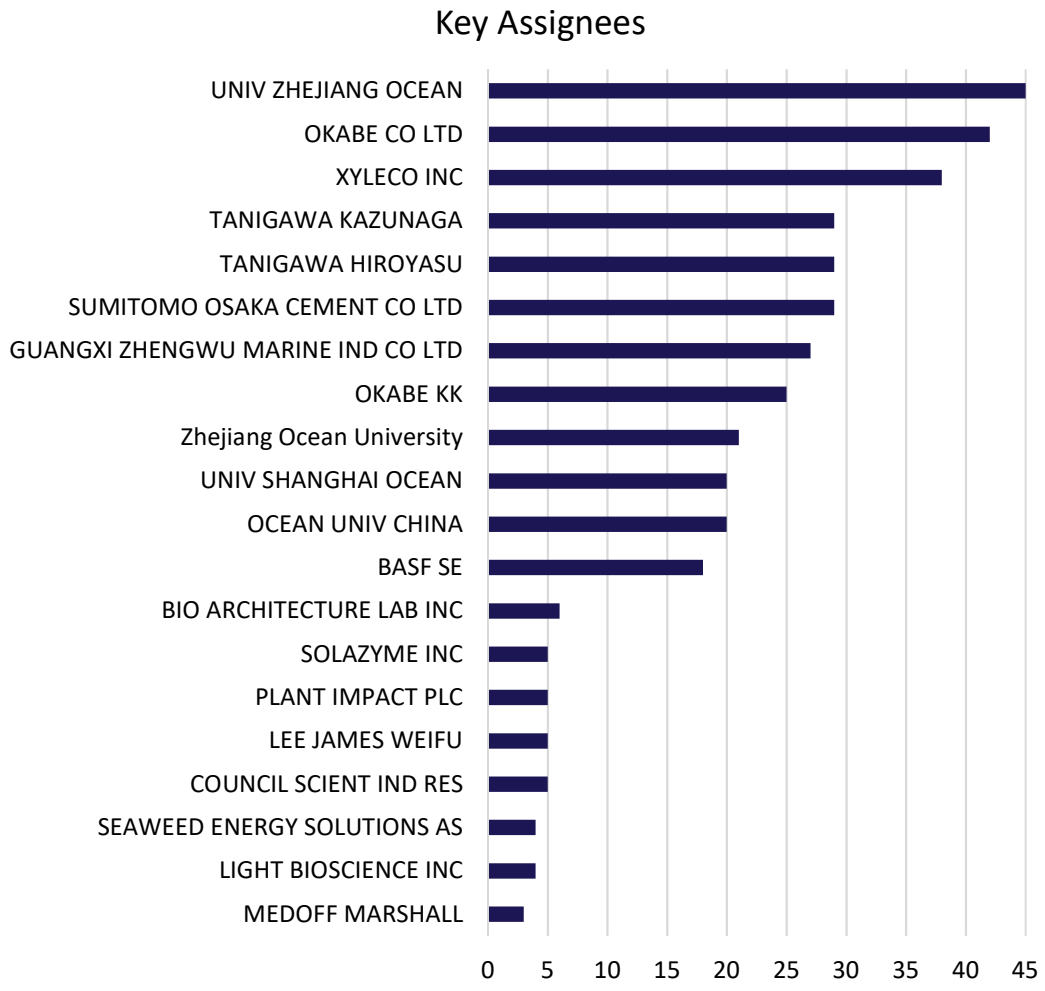

Figure 2: Key assignees for patent families in seaweed farming/harvesting

Unsurprisingly, the countries of China, Japan and Korea account for over 80% of patents filed. This data was further analysed to identify the priority countries where the patents are initially filed. This gives an indication of where most invention is taking place, as patents are commonly filed in the home territory of the inventing company or organisation. Again, China, then Japan, followed by the US and Korea are by far the most important territories for innovation. The graph also includes the UK in the top 10 priority countries suggesting some R&D in the country.

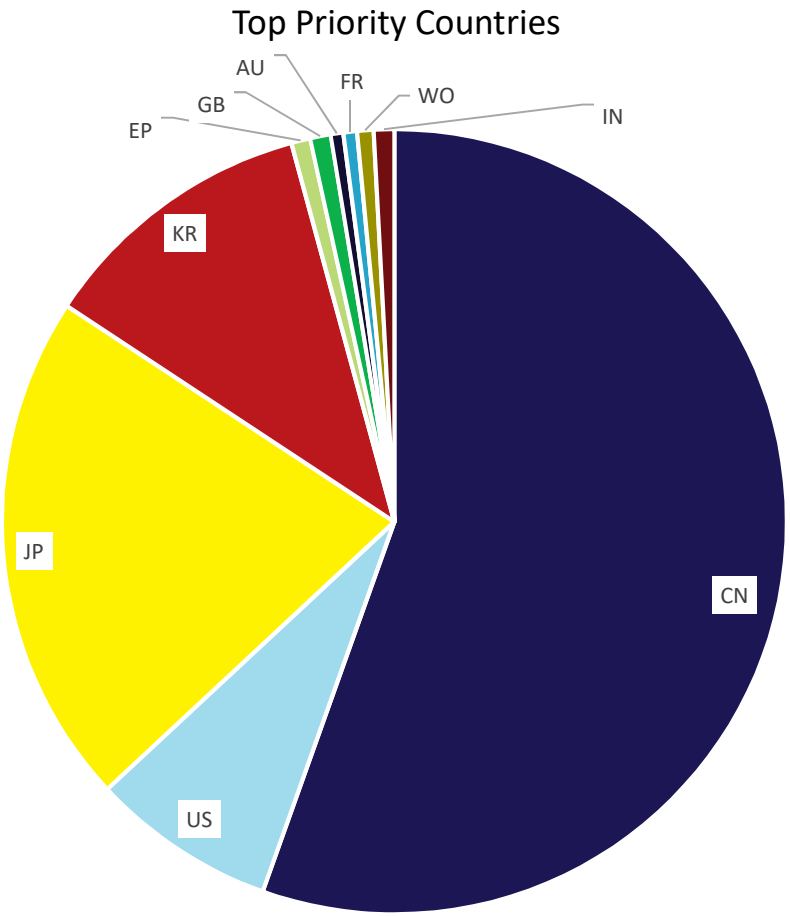

Figure 3: Top priority countries for patent protection

4.2 PATENT LANDSCAPING

Thomson Innovation can be used to generate sophisticated patent landscapes to visualise the relationship between patents in a common field based on key words within the claims and/or abstracts/text of individual patents within the searched field. This can be used to locate competing or similar patents to the patents of interest. As with a geographic landscape the contour lines and intensity of peaks on the patent landscape represent areas of high patent activity with closely related concepts.

The patent set from the broad search was mapped using Thomson Innovation's proprietary ThemeScape™ mapping tool. ThemeScape uses term frequency and other algorithms to cluster documents based on shared language – in this case the English Title, Abstracts and Claims from the patents together with the DWPI-enhanced Titles and Abstracts were mapped. It uses several algorithms to perform terminology-based clustering. The text from one record is compared with the text from all other patent records within the search collection. The map uses vectors to give each patent record a proximity score to all of its peers. The outcome of this analysis is a visualisation of the patent space with each patent (dot) represented once in the map, with patents in close proximity

sharing more phraseology than those located apart. Each peak is labelled with the key terminology concepts contained in the patents within the cluster. The resulting maps are shown below.

The map is dominated by organisations primarily protecting novel formulations in fertilisers or animal feed, specific aspects of biomass processing or energy production, or practical aspects/mechanisms in seaweed farming. The Chinese dominance of the patent landscape is reflected by a number of patents relating to Chinese herbal medicines.

A series of sub-searches were carried out on the broad search to narrow down the results and identify any patents or patent applications that are relevant to the Client's interests in seaweed farming. Important keywords were used to search for relevant patent cases within the landscape and the visual results of these searches are shown on two separate maps in sections 4.2.2 and 4.2.3. The patent publications shown as coloured dots correspond to the keywords in the key. Patent publications containing two or more of the keywords are displayed as a white dots. Further analyses of the sub-searches and their results are detailed in section 4.3.

4.2.1 PATENT LANDSCAPE MAP: SEAWEED FARMING

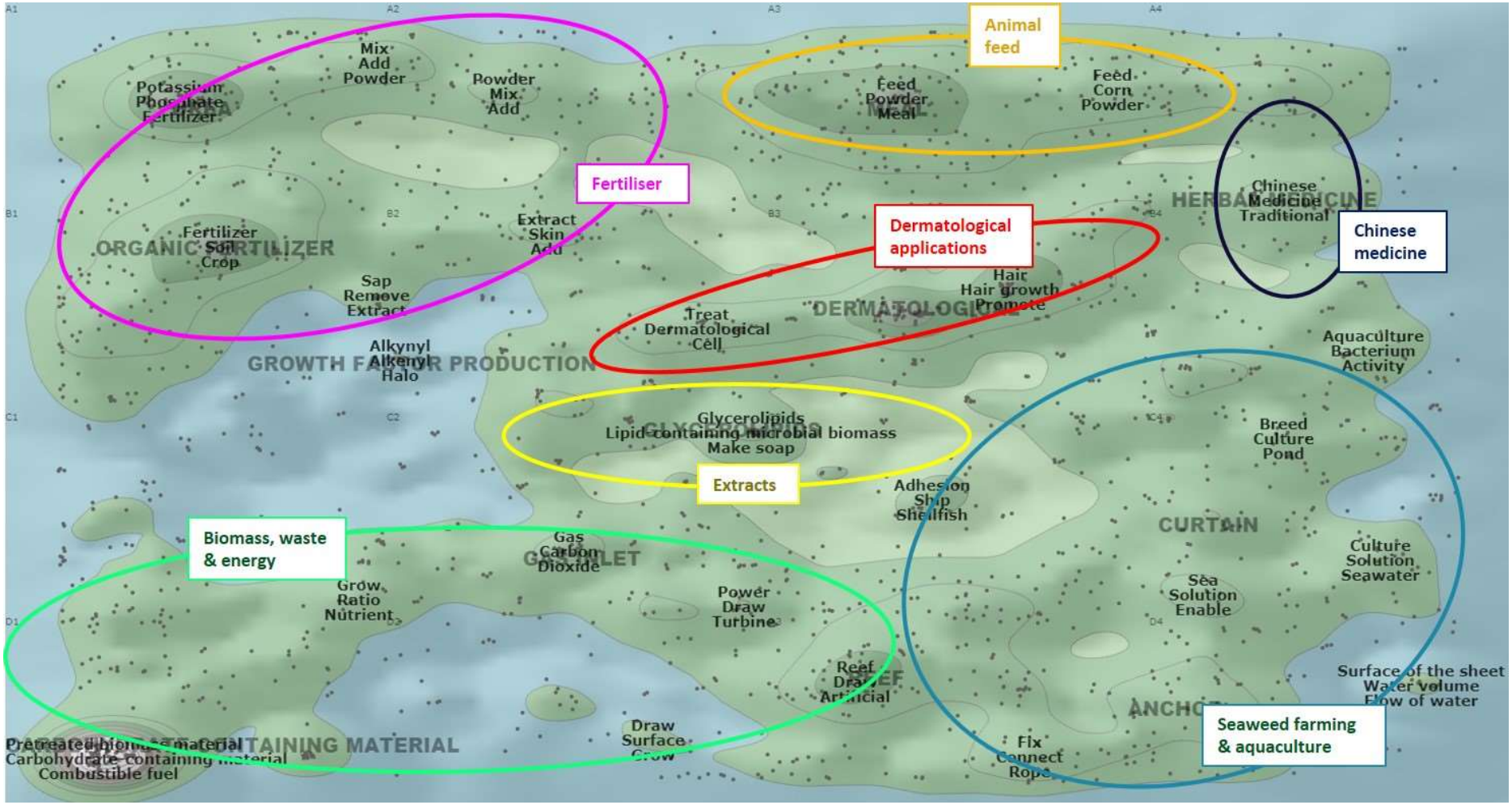

Figure 4: Patent landscape for seaweed farming/harvesting

4.2.2 PATENT LANDSCAPE MAP: SEAWEED FARMING & BIOENERGY

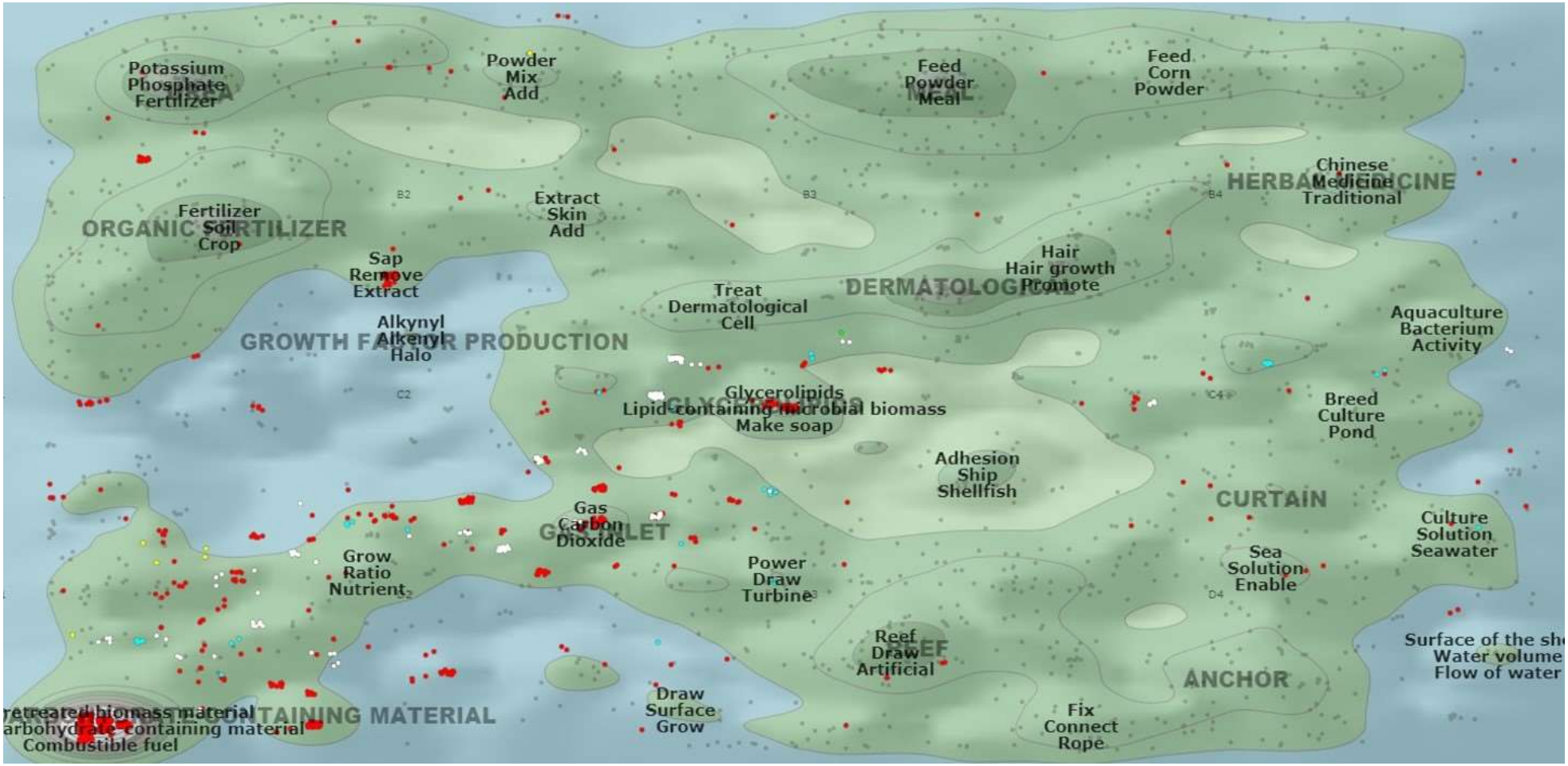

Figure 5: Patent landscape for seaweed farming/harvesting and bioenergy. Key: red = "biomass"; blue = "biofuel"; yellow = "anaerobic ADJ digest*"; green = "bioenergy"; white = multiple keyword matches

4.2.3 PATENT LANDSCAPE MAP: SEAWEED FARMING & EXTRACTS

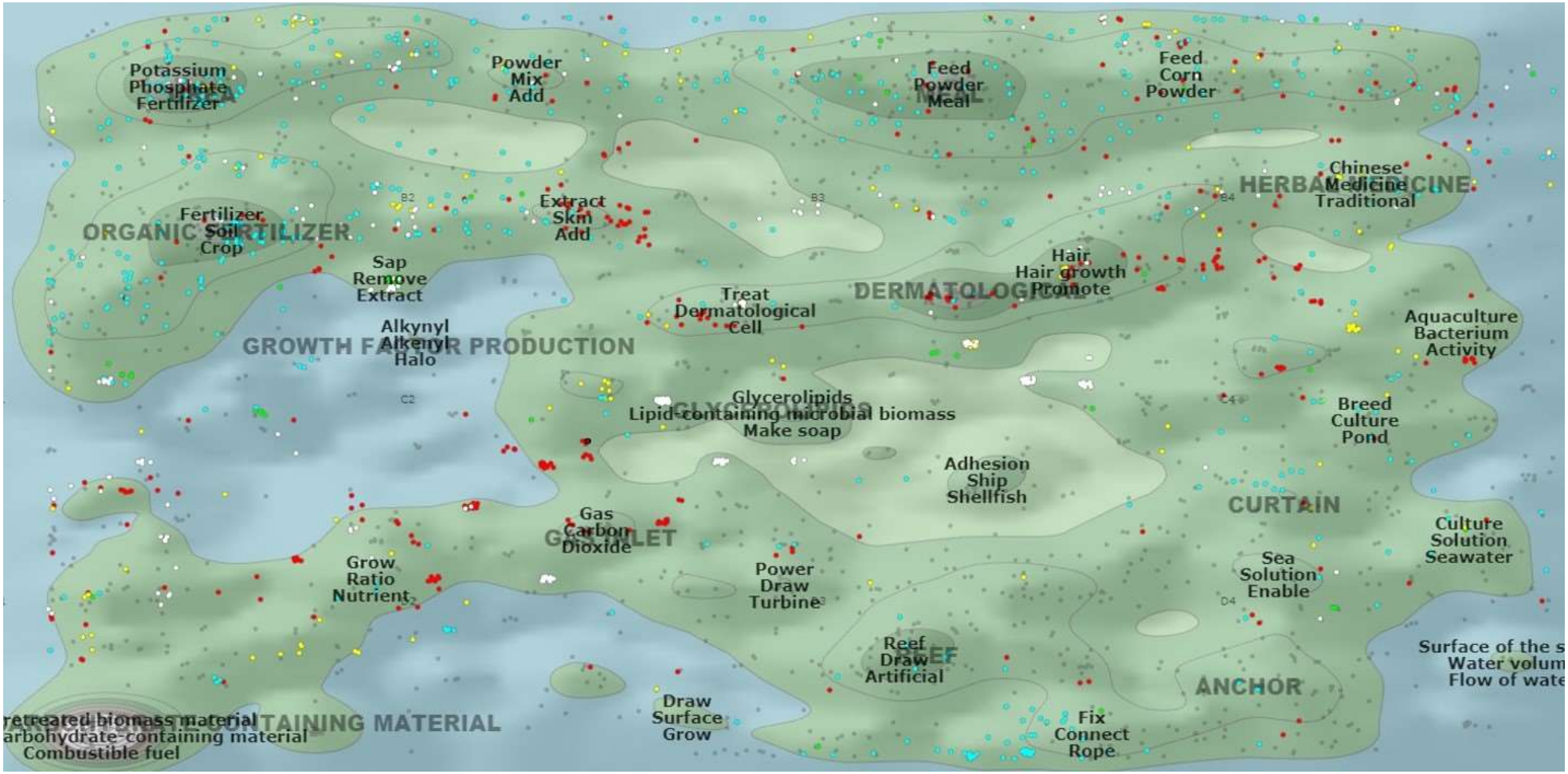

Figure 6: Patent landscape for seaweed farming/harvesting and biotechnology. Key: red = "extraction"; blue = "alginate*"; yellow = "agar"; green = "carrageenan"; white = multiple keyword matches

4.3 SUB-SEARCHES

Any pertinent patent cases that were identified during the focussed searches have been summarised in the following sections. For each search, the full details of these cases are included in spreadsheets along with the details of the other related cases identified in the search.

Note: To access the full text of these patents, please click on the hyperlinked publication number within the spreadsheets to retrieve a summary of the patent. A pdf of the original file can then be downloaded by clicking the pdf logo located just to the left of the words "Full View" at the top left of the screen.

4.3.1 BIOENERGY

The keywords used to identify macroalgae bioenergy patents were "bioenergy OR biofuel* OR (anaerobic ADJ digest*) OR biogas OR biomass". The search identified 381 patent families:

bioenergy.xlsx

Most patents found relate to fertiliser production or biomass treatment. There are a number of patents of potential relevance and should be reviewed by the Client – those potentially relevant to GreenSeas's interests specifically in seaweed farming/harvesting have been highlighted in yellow.

4.3.2 BIOTECHNOLOGY

The keywords used to identify macroalgae biotech and high-value extract patents were "hydrocolloid* OR agar OR carrageenan* OR extraction". The sub-search identified 485 patent families. The search terms "extract*" and "alginate*" were not used as they are too broad, returning many hundreds of results of low relevance, which span many different applications (as highlighted by the landscape map in Section 4.2.3).

biotech.xlsx

Most patents found relate to fertiliser production, biomass treatment or cosmetic extracts. There are a number of patents of potential relevance to the Client – those potentially relevant to GreenSeas's interests specifically in seaweed farming/harvesting have been highlighted in yellow.

4.3.3 FOCUSSED SEARCH FOR COMPETITOR PATENTS

A series of searches were carried out in order to identify patents or patent applications owned by the organisations with competitive seaweed farming operations. The search only identified a patent belonging to Marine Biopolymers (who are of interest to the Client but not a direct competitor), relating to a Method for Processing Seaweed and Related Products:

WO2015067971(A1).pdf

5 THE MARKET POTENTIAL

5.1 MARKET OVERVIEW AND OPPORTUNITIES

Seaweed (macroalgae) has a wide range of uses, and demand has increased all over the world during the last half-century. To meet this new demand has required a change in production methods. Wild stocks are limited, so seaweeds have been cultivated instead. Global seaweed production has more than doubled between 2000 and 2014, from 10.5 to 28.4 million tonnes. The 2012 world production of seaweeds was estimated to be about $6 billion; 95% of this production was from Asian aquaculture, predominantly China.[3] In terms of farmed (rather than wild) seaweed, just 7 countries (China, Indonesia, Philippines, South Korea, North Korea, Japan and Malaysia) account for 99.3% of world production.

Aquaculture is the main source of production of marine plants for Africa and Asia, contrarily to America and Europe where production is almost entirely from harvest of wild plants. The majority of marine plants produced globally are red and brown seaweeds (97.4%). In particular, red seaweeds production has globally increased by 84% in the period 2010-2014, while brown seaweeds production increased by 47% in the same period. Contrarily global green seaweeds and miscellaneous aquatic plants productions decreased 30% and 79% respectively between 2010-2014.

There has not been a long history of seaweed farming in the UK. However, in recent years, there has been more interest in seaweed aquaculture, mainly driven by research into algal biofuel technologies. Seaweed farms could become an important source for third generation biofuels production as its aquaculture does not compete for land and freshwater with either food or non-food crops. Furthermore, seaweeds have high productivity, fast growth rates and high polysaccharide content; all important qualities for biomass for biofuels.

Multiple products can be obtained from seaweeds, ranging from food to chemicals and bioenergy. For the UK, a total of 27 seaweed-related businesses were identified in a 2016 DEFRA report[4], based on web searches; 16 of them use seaweeds harvested in the UK. The majority of UK seaweed-related businesses produce seaweeds for food (or “sea vegetables”) or condiments, and for cosmetics. Other products, based on seaweeds and produced in the UK, include animal feed and supplements, chemicals (i.e.. hydrocolloids), fertilizers and nutraceuticals (e.g. nutrients and dietary supplements). Production of seaweeds for other uses such as bioremediation, or biofuel production (via anaerobic digestion), is at the development stage.

Pilot seaweeds farms are currently developing in the UK with pilot facilities established in Northern Ireland (Queen’s University, Belfast), Scotland (SAMS), Shetlands (University of Highlands and Islands) and, from this year, Wales (Swansea University). Due to its extensive coastline, seaweed production

[3] http://www.un.org/Depts/los/global_reporting/WOA_RPROC/Chapter_14.pdf

[4] DEFRA (2016) *Seaweed in the UK and abroad – status, products, limitations, gaps and Cefas role*

in the UK could be increased beyond the current level. This is likely to occur through farming as wild harvest is close to maximum capacity at locations with current activity.[5]

An overview of the production chain for seaweed products relevant to the Client is shown in Figure 7, below (source: DEFRA report[4,6]). Seaweed production in the UK would benefit from a bio-refining approach to reduce waste and obtain various products from algal biomass, as summarised in Figure **8**.

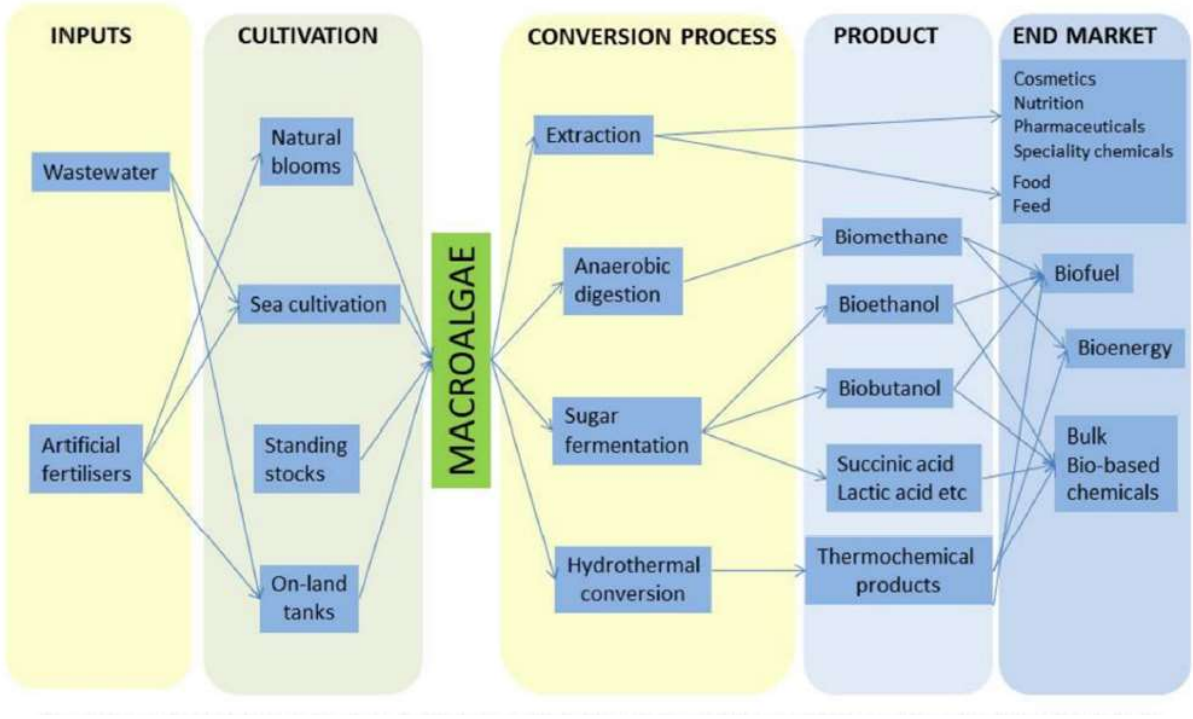

Figure 7: Algal Biofuel and Bioenergy Pathways[4,6]

[5] AB-SIG (Algal Bioenergy Special Interest Group) (2013). *A UK roadmap for algal technologies.*

[6] NNFC (2012). *Research Needs in Ecosystem Services to Support Algal Biofuels, Bioenergy and Commodity Chemicals Production in the UK*

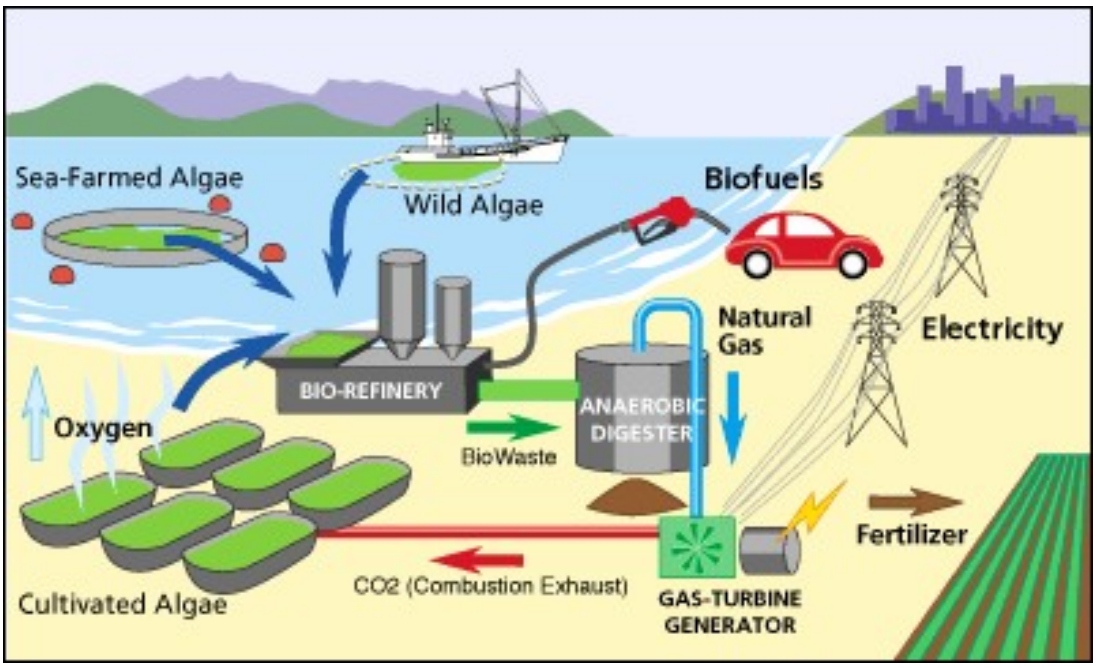

Figure 8: Cartoon schematic of seaweed biorefining approach (Source: Innovate Development[7])

This is particularly important when considering the pricing of products produced from seaweeds, as shown in Figure 9. Energy, feed and bioremediation require large volumes of algae but the economical return for the biomass is small (<£1/kg). Contrarily, when algal components are used in speciality products, nutraceuticals and cosmeceuticals, the value of algal biomass can become substantially higher, worth over £2000/kg for nutraceuticals and cosmetics, and over £5000/kg for some speciality applications. A bio-refining approach would allow production through the range of products of the pyramid shown below, allowing access to different markets. Currently UK capacity for seaweed production is positioned between the 'added value commodities' and 'speciality products' sections of the pyramid below, with values between £1-1000/kg.

[7] http://innovatedevelopment.org/2014/04/13/seaweed-biofuel-promotes-island-self-sustainability

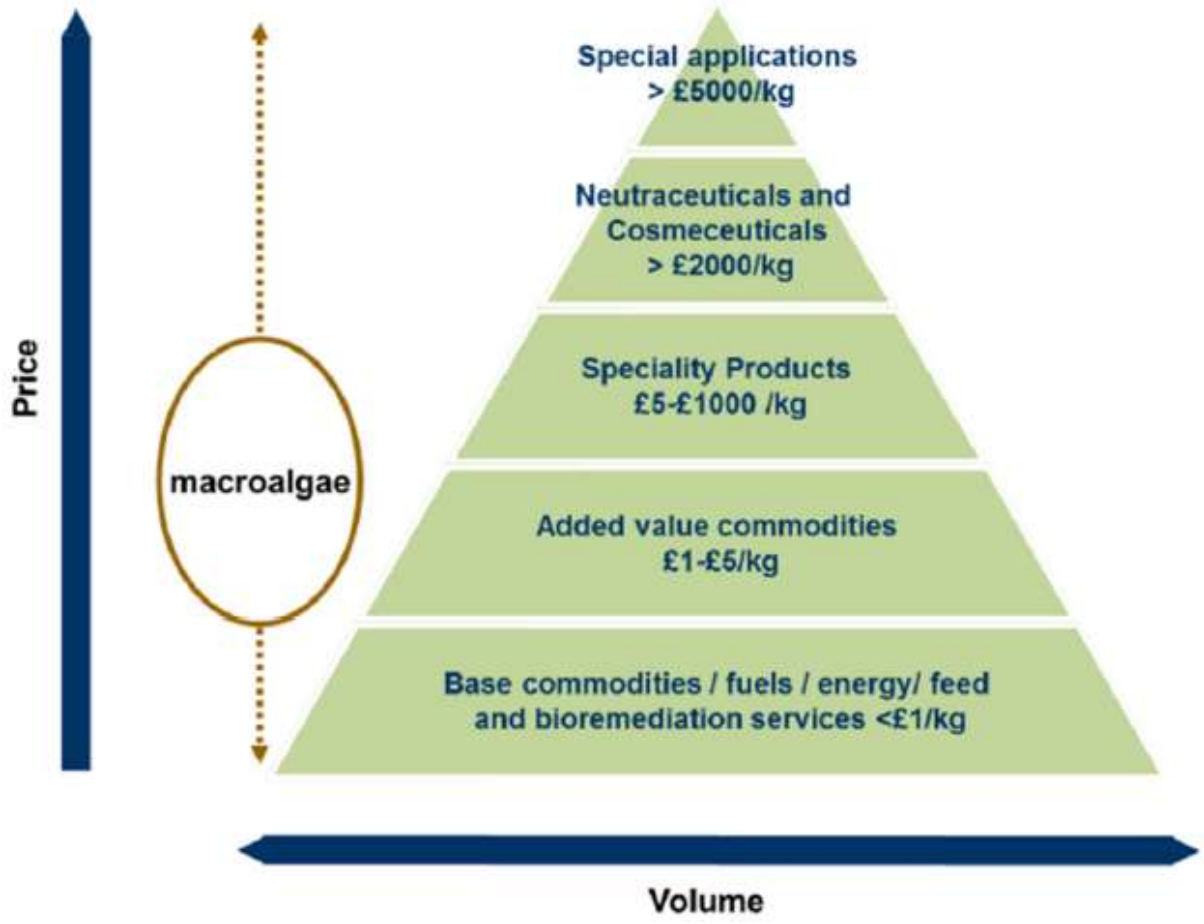

Figure 9: Pricing of products from macroalgae and current capacity for macroalgae production in the UK.[4]

5.1.1 BIOENERGY

Seaweeds could become an important source for third generation biofuels production as they do not compete for land and freshwater with food crops and non-food crops. Furthermore, seaweeds have high productivity, fast growth rate and high polysaccharide content. The latter is particularly important as seaweeds can be fermented to produce bioethanol or butanol, or used for generation of biomethane via anaerobic digestion (AD).

In order to reduce costs for production of algal biomass, there should be minimal waste and all algae biomass should be developed into a product that can be sold. This could be achieved with an integrated bio-refinery capability. Following this approach seaweed growth would be fed, for example, by waste water (bioremediation); the harvested biomass would be stripped of all the important components (e.g. carbohydrate, protein) which could be used for different products, and only the residual biomass would be used for generation of biogas via AD. Biofuels production from macroalgae is still under development; in fact, aspects such as storage and pre-treatment of seaweeds, or economic viability of the supply-production chain, need further investigation. Examples of current projects in the UK which are addressing these aspects are discussed in Section 5.5.

Figure 10 illustrates how algal biomass can be converted to energy. Most favourable will be those pathways which do not require the energy-intensive step of drying the biomass, such as AD and liquefaction. Conversion into methane through AD is the most feasible use of seaweed for bioenergy.

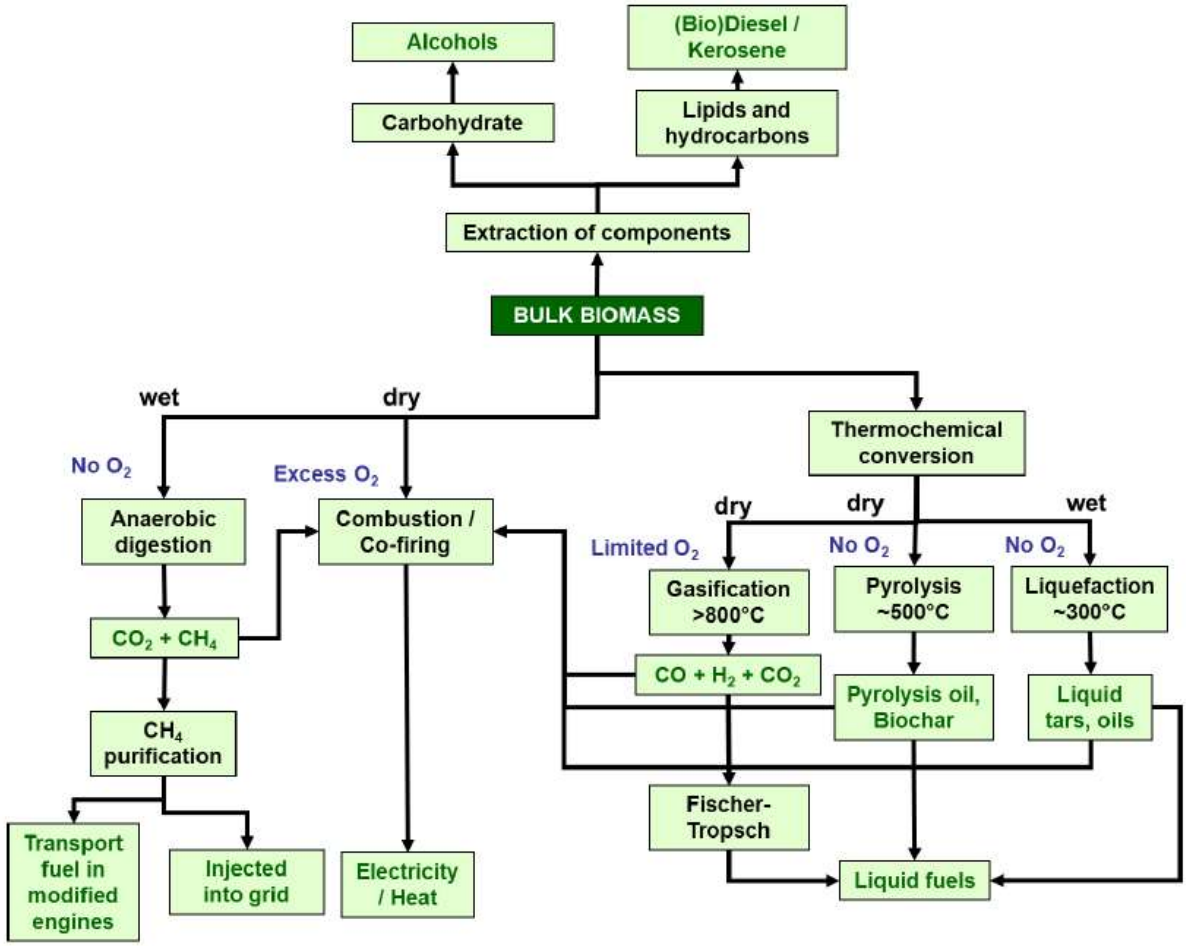

Figure 10: Biomass processing options (simplified) for energy products[5]

Though AD is already a highly sustainable process, the use of macroalgae is in general still a developing field, which is several years from adoption (though small scale addition to existing AD facilities could start immediately), so market projections are still unclear, though bioenergy applications of seaweed should be considered a medium- to long-term option. Even if this sector doesn't develop in the UK, there is the opportunity for the development of UK technology and revenue generation through licensing and deployment of this technology abroad.

Macroalgae are rich in carbohydrates, and as such there will be potential routes for the development of fermentation based fuels such as biobutanol and bioethanol, which can be blended into transport fuels as a renewable biofuel. Internationally, there is an increasing research effort in this area. Bio Architecture Labs (BAL) and Dupont have received funding from the US Department of Energy to

develop the production of biobutanol from macroalgae, which will be commercialised by Butamax. However, this is a long-term market, with at least 10 years until it can be realised.[6,8]

5.1.2 BIOTECHNOLOGY

Hydrocolloids are used in the food, cosmetic and medical industries. Alginates are extracted from brown seaweeds, while carrageenan and agar from red seaweeds. These three components (polysaccharides) can bind water and form hydrogels which are then used as additives and stabilisers in different sectors.

Alginates are derived from brown seaweeds and are produced mainly in the USA, Norway, China, Canada, France and Japan. They are used in food as thickeners, gelling and stabilizers for different products from ice cream to beers. Carrageenans are extracted from red seaweeds and Indonesia is the main producer of farmed red seaweeds. Carrageenans have protein-binding properties therefore it is used in the dairy sector as stabiliser. Other industrial uses of this hydrocolloid are in shampoos and toothpastes. The global demand of agar (another hydrocolloid extracted from red seaweeds) is mainly covered by Chile, India, Mexico, California, South Africa and Japan. It is a versatile food addictive (thickening and emulsifying agent) as it has no taste, smell or colour; and it is also used as cultivation medium for bacteria in laboratories.

Seaweeds, added to soil as compost, or dried as amendment, or with no pre-treatment, are beneficial to the growth of plants (e.g. tomatoes, corn). Macroalgae have higher concentration of Ca, K, Mg, Na, Cu, Fe, I and Zn compared to terrestrial plants, and their organic compounds can be used as energy source for microbes. Seaweeds as soil conditioners have the ability to make the soil more porous which allow water and air to penetrate through.

The global seaweed hydrocolloid market is worth around $1 billion, with the carrageenan market having the largest share, of 49.8% in 2014, followed by the alginates market and agar market with market shares of 31.6% and 18.6%, respectively, as shown in the Table below.[9]

[8] http://biofuels-news.com/display_news/10978/seaweed_farms_could_become_important_source_for_biofuels_production_in_uk_report_suggests/

[9] BCC Research (2016) *Hydrocolloids: Technologies and Global Markets*

GLOBAL MARKET VALUE FOR SEAWEED HYDROCOLLOIDS BY TYPE, THROUGH 2020
($ MILLIONS)

Type	2014	2015	2020	CAGR% 2015-2020
Carrageenan	486.4	498.8	594.7	3.6
Alginates	308.0	321.4	374.1	3.1
Agar	181.7	186.4	207.0	2.1
Total	976.1	1,006.6	1,175.8	3.2

Source: BCC Research

The global alginate market is expected to increase from 27.5 thousand metric tons, valued at $308.0 million, in 2014 at a YOY growth rate of 4.4%, in terms of value and volume, to reach 28.7 thousand metric tons, valued at $321.4 million, in 2015. Further, the market is estimated to grow at a five-year CAGR (2015 to 2020) of 3.1%, in terms of value and volume, to reach 33.4 thousand metric tons, valued at $374.1 million, in 2020. The increase is due primarily to increasing applications for alginates in the cosmetics industry.

The global carrageenan market is expected to increase from 51.2 thousand metric tons, valued at $486.4 million, in 2014 at a YOY growth rate of 2.5%, in terms of value and volume, to reach 52.5 thousand metric tons, valued at $498.8 million, in 2015. Further, the market is estimated to grow at a five-year CAGR (2015 to 2020) of 3.6%, in terms of value and volume, to reach 62.6 thousand metric tons, valued at $594.7 million, in 2020. The increase is attributed to increasing use of carrageenan in dairy products.

The global agar market is expected to increase from 11.5 thousand metric tons, valued at $181.7 million, in 2014 at a YOY growth rate of 2.6%, in terms of value and volume, to reach 11.8 thousand metric tons, valued at $186.4 million, in 2015. Further, the market is estimated to grow at a five-year CAGR (2015 to 2020) of 2.1%, in terms of value and volume, to reach 13.1 thousand metric tons, valued at $207 million, in 2020. The increase is attributed to increasing applications in meat-related products.

The applications of hydrocolloids are provided in the tables below, with projections of the market volume of each, and the value to key end user industries.[9]

GLOBAL ALGINATE MARKET VOLUME BY FUNCTION, THROUGH 2020 (THOUSAND METRIC TONS)

Function	2014	2015	2020	CAGR% 2015-2020
Gelling agent	11.2	11.8	13.3	2.4
Thickener	10.5	10.7	12.2	2.6
Stabilizer	3.1	3.4	3.9	3.1
Film-forming/coating material	1.7	1.8	2.5	6.8
Fat replacer	0.3	0.3	0.4	4.6
Other	0.7	0.7	1.1	9.5
Total	27.5	28.7	33.4	3.1

GLOBAL ALGINATE MARKET VALUE BY END-USER INDUSTRY, THROUGH 2020 ($ MILLIONS)

End-User Industry	2014	2015	2020	CAGR% 2015-2020
Cosmetics and textile printing	131.0	135.5	162.4	3.7
Food and beverage	110.9	115.4	126.6	1.9
Pharmaceuticals	31.4	33.6	42.6	4.8
Paper treatment	14.6	15.7	19.0	4.0
Other	20.1	21.2	23.5	2.0
Total	308.0	321.4	374.1	3.1

GLOBAL CARRAGEENAN MARKET VOLUME BY FUNCTION, THROUGH 2020 (THOUSAND METRIC TONS)

Function	2014	2015	2020	CAGR% 2015-2020
Gelling agent	23.5	23.9	28.6	3.7
Stabilizer	14.0	14.3	15.9	2.1
Thickener	9.2	9.4	10.5	2.2
Film-forming/coating material	1.5	1.7	3.1	12.8
Fat replacer	0.6	0.7	1.5	16.5
Other	2.4	2.5	3.0	3.7
Total	51.2	52.5	62.6	3.6

GLOBAL CARRAGEENAN MARKET VALUE BY END-USER INDUSTRY, THROUGH 2020
($ MILLIONS)

End-User Industry	2014	2015	2020	CAGR% 2015-2020
Food and beverage	378.1	383.8	435.1	2.5
Pharmaceuticals	56.9	61.8	93.1	8.6
Cosmetics and textile printing	12.4	13.3	20.0	8.4
Other	39.0	39.9	46.5	3.1
Total	486.4	498.8	594.7	3.6

GLOBAL AGAR MARKET VOLUME BY FUNCTION, THROUGH 2020
(THOUSAND METRIC TONS)

Function	2014	2015	2020	CAGR% 2015-2020
Gelling agent	7.6	7.7	8.1	1.0
Stabilizer	1.9	2.0	2.2	1.9
Thickener	0.8	0.8	1.0	4.6
Film-forming/coating material	0.2	0.3	0.5	10.8
Fat replacer	0.2	0.2	0.4	14.9
Other	0.8	0.8	0.9	2.4
Total	11.5	11.8	13.1	2.1

GLOBAL AGAR MARKET VALUE BY END-USER INDUSTRY, THROUGH 2020
($ MILLIONS)

End-User Industry	2014	2015	2020	CAGR% 2015-2020
Food and beverage	137.5	139.0	150.1	1.5
Pharmaceuticals	28.4	30.0	34.8	3.0
Cosmetics and textile printing	4.7	6.3	7.9	4.6
Other	11.1	11.1	14.2	5.2
Total	181.7	186.4	207.0	2.1

Source: BCC Research

5.2 MARKET DRIVERS

Considering the length of its coastline, the UK has a great potential to extend the macroalgae industry. Currently, seaweed biomass produced in UK is mainly collected from natural resources; wild harvest could potentially be increased or extended to new sites, but the potential for farmed seaweed to make an impact in key user markets is high.

Alginate production is the main end product of seaweeds in Europe, however there is currently substantial competition with Asia as provider of raw seaweed biomass. Local seaweed production in Europe is not enough to meet the high demand of processing industries, particularly for alginates. In fact, existing processing industries in France, Norway and Ireland use local raw materials but need to import dried seaweeds when local supplies are out of season or not enough to meet demand. Therefore, there is demand for farmed seaweed in Europe, but it is unlikely the European alginates and carrageenan industries will look to algae biomass from seaweed farmed in Europe when wider (and cheaper) resources are available in South Africa, Chile, Argentina, and Asia[10], so European supplies must be competitive.

Within the European seaweed industry, there is currently a lack of a diversified market for seaweeds, but current drives to opening new markets (e.g. sea vegetables, biotech or biofuels) may help push forwards and reinvigorate the European seaweed production. Importantly, development of the sector should be towards a sustainable seaweed production.[11] This is particularly important for end-user industries of seaweed extracts in Europe, such as packaging and cosmetics, where there is growing demand for natural product-based materials and companies are increasingly eco-conscious.

The largest market pull is found for products and services that in the current techno-economic assessments are most challenging to achieve: biofuels, bulk feed and chemicals, and large scale bio-remediation, e.g. for CO2 capture and storage.[5]

The UK has expertise in the environmental and ecological sector for macroalgae. Algal culture collections (though predominantly microalgae) in the UK are highly regarded internationally and UK experience in algal taxonomy, physiology, metabolism, biochemistry and molecular biology is a key strength. In addition, the UK is well placed to produce technologies associated with the scaling up of algal growth (e.g. optimising productivity, lowering costs for growth, harvesting and processing.[5] However, continuity of funding is essential to maintain this advantage: both R&D funds to attract and retain academic excellence, and resources to provide continuity and expansion of the support network that facilitate successful project development between academia and industry, will be essential if the UK is to establish a globally competitive algal commercial sector.

[10] http://www.seaweed.ie/uses_ireland/irishseaweedaquaculture.php

[11] Netalgae (2012). *Seaweed Industry In Europe*

5.3 BARRIERS TO ENTRY

There are various issues and barriers limiting or affecting the development of seaweed production and markets. In Europe and the UK, there is a perceived bottleneck in the seaweed supply chain in terms of production capacity (result of high costs for seaweed biomass production compared to Asia and/or shortage of seaweed biomass due to seasonality).

There is the need to establish how macroalgae cultivation can be done at a large scale in an environmentally and economically sustainable manner. Determination of suitable locations for farm sites or harvesting which could also lead to potential conflicts with other uses of the coastal area; for example, in Asia seaweed farms can compete for shallow coastal areas with tourism.

Seaweeds aquaculture could contribute to meet the demand for algal biomass; however, factors such as lack of information on operational costs, potential biomass yields and ecological effects of seaweeds farms, are perceived to limit the development of the seaweed aquaculture industry. Regulatory/licensing of the cultivation and sale of seaweed (unclear process for obtaining licence, lack or unfit regulation specific to seaweed) is a widespread issue, for the Asian as well as for European and UK production.

Set-up requirements, such as robust algal cultivar availability (e.g. for the development of algal strains with higher growing rates or resistant to higher water temperatures), infrastructure and storage capabilities, availability of capital/investment, and unclear end-user markets, as with all businesses entering a nascent market, can be challenges. There are also issues with a lack of awareness of the industry and an associated shortage of available and shareable technical know-how and skills on seaweed farming – this has been identified as a key issue for seaweed farming in India, Indonesia, Mexico, Philippines and Solomon Islands.[12]

In the UK, key issues are distant interactions and knowledge transfer between academia, chemical and end-user industries, a lack of algal bio-business incubators and clusters, and poor public awareness and acceptance. There is also the requirement to develop supply chains matched to production capacities and increase the visibility of UK expertise and products at global level. There is a need to provide clarity about the regulatory context, in particular, clearer marine licensing procedure for offshore cultivations.

Currently, in the UK, there is a bottleneck in the seaweed supply chain in terms of production capacity; companies are interested in algal biomass but they are held back by high costs and/or by shortage of supply. This is a similar situation to the one observed in Europe, resulting in a reduction of processing industries for seaweeds. In recent years, large multinationals (such as Cargill, FMC, International Speciality Products (ISP; part of Ashland), who dominate alginate and carrageenan production in the UK) have sourced factories in developing world countries or, as in the case of the ISP factory in Girvan

[12] Valderrama et. al. (2013) *Social and economic dimensions of carrageenan seaweed farming*, FAO Fisheries and Aquaculture Technical Paper No. 580

(Scotland), downgraded it from production to product blending/finishing, with production moved to Norway and with raw material supply coming from Iceland.

The challenges associated specifically with bioenergy production from seaweed are mostly logistical issues associated with an early-stage market. The main challenge is identification of how anaerobic digestion could be integrated into a biorefinery. For example understanding the extent to which residues from the extraction of specific materials and compounds could be used to feed anaerobic digesters considering the variation in chemical composition and volume between the residues.

It is also required to establish to what extent macroalgae can be used in conjunction with other organic waste streams to achieve economies of scale in production or favourable economics, especially if there is a large disparity in scales between the amount of macroalgae residues produced from high value product isolation and the scales needed for anaerobic digestion. Another issue is to identify potential markets for the digestate product other than simply spreading to land. Identification of new potential digestate produce markets would help overcome the current problem faced by farmers using digestate.

5.4 GEOGRAPHICAL DISTRIBUTION

As discussed above, Asia dominates the global production of aquatic plants, as shown in the Figure below. China alone accounted for 50.8% of production, while Indonesia for 30.8%. The only non-Asian countries ranked in the top 10 aquatic plant producers are Chile (2% of world production in 2013), Norway (0.6%) and Zanzibar (0.4%). The UK's seaweed production is lower still. Within the UK, Scotland is currently leading the way in seaweed research, and where the Government has recently published guidelines on seaweed harvesting policy.[13] Northern Ireland and Wales are taking an active role in looking at the benefits of seaweed, with comparatively less activity in England.[14]

[13] http://www.gov.scot/Publications/2017/03/1340

[14] http://www.theecologist.org/green_green_living/2988214/biofuels_from_seaweed.html

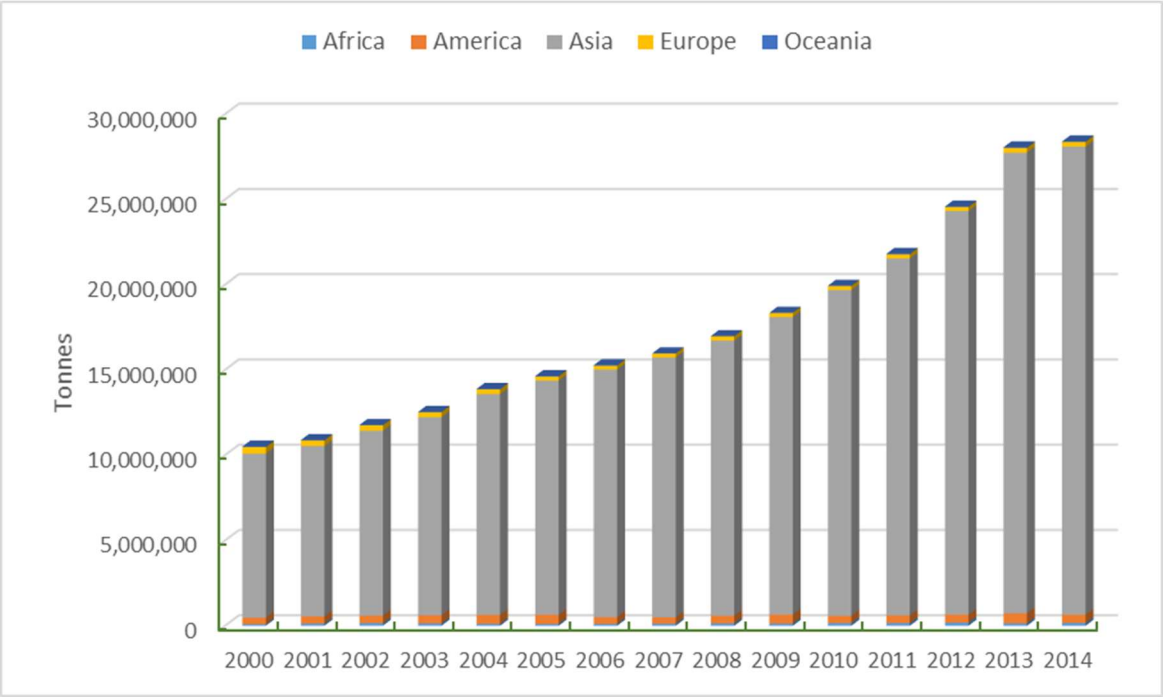

Figure 11: Cumulative annual world aquatic plant production (tonnes).

Aquaculture is the main source of production of marine plants for Africa and Asia, contrarily to America and Europe where production is almost entirely from harvest of wild plants. Alginates are derived from brown seaweeds and are produced mainly in the USA, Norway, China, Canada, France and Japan. Carrageenans are extracted from red seaweeds, of which Indonesia is the main producer. The global demand of agar (another hydrocolloid extracted from red seaweeds) is mainly covered by Chile, India, Mexico, California, South Africa and Japan.

Though the largest producer of seaweed, demand in Asia is mostly for food. Asia has the largest market share of the global seaweed hydrocolloid market with about 30.2%, in terms of value, closely followed by Europe with a market share of 29.8%. BCC Research's projections for global seaweed hydrocolloid market revenue by region are shown in the following Figure.

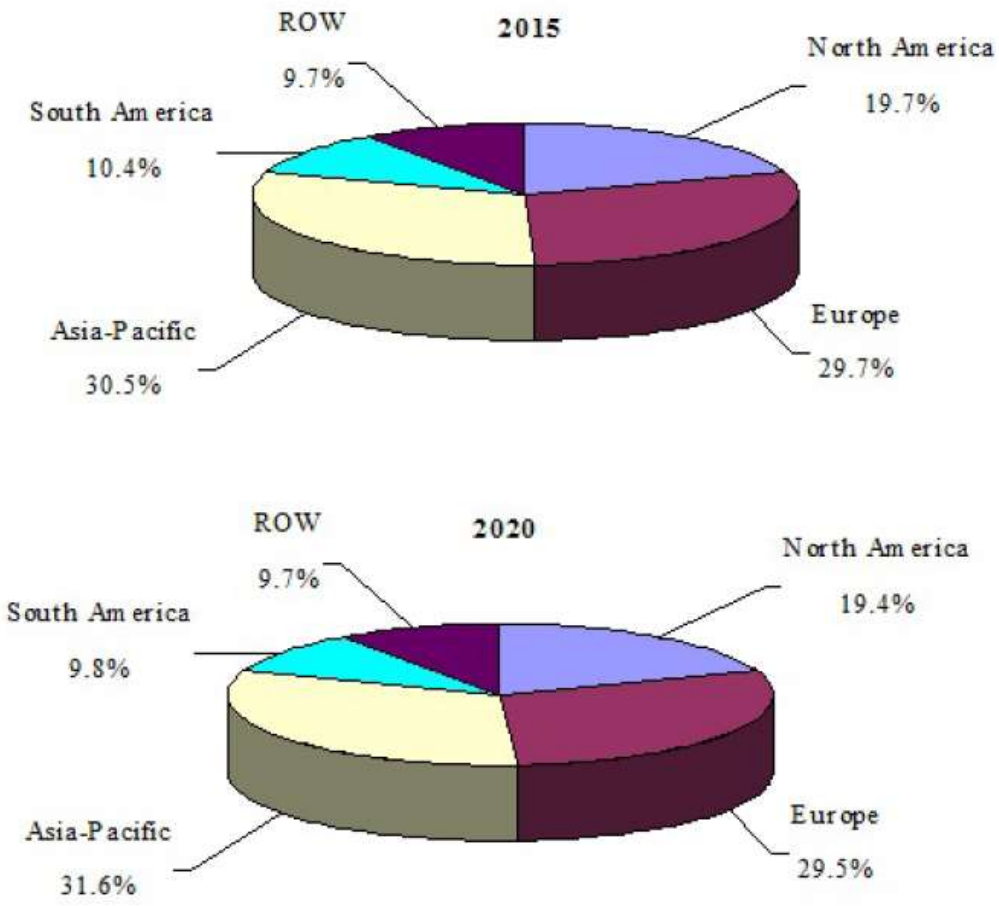

Figure 12: Global market value share for seaweed hydrocolloids by region, 2015 & 2020 (%). Source: BCC Research[9]

5.5 KEY PLAYERS

Pilot seaweeds farms are currently developing in the UK with pilot facilities established in Northern Ireland (Queen's University, Belfast), Scotland (SAMS), Shetlands (University of Highlands and Islands) and, from this year, Wales (Swansea University). These pilot farms have been producing seaweeds (mainly brown seaweeds such as *Saccharina latissima*, sugar kelp) as part of different projects (e.g. SeaGas, MacroFuel, MacroBioCrude) to investigate the potential use of seaweeds as source for biofuel, chemicals and speciality products. For example, seaweeds grown in Scotland at the SAMS pilot farm are used in the SeaGas and Macrofuel projects. An overview of the main current and recent projects related to seaweeds, where all or some of the project partners are UK organisations, is shown in the table in section 5.5.1 below.

Macroalgae farming is not very well developed in Europe in general. The largest producers are Norway, France and Ireland, with some activity in Iceland, Denmark, Spain, Portugal and the UK.[15] Much of the European seaweed farms are currently still at the experimental stage, as part of collaborative European public-private research programmes. Commercial aquaculture of seaweed is found mostly in France and Spain. The leading UK seaweed farm, at a 100 hectare site run by SAMS off the island of Lismore, has recently entered a trial to cultivate seaweed commercially.[16]

Sixteen UK businesses using UK seaweed supplies were identified in a 2016 DEFRA report.[4] The majority of companies (8) produce seaweeds for food or condiments. The second most common use of seaweeds was for production of cosmetics and nutraceuticals, followed by animal feed production and fertilisers. It appears just two businesses produce alginate and there is only one commercial seaweed hatchery. The majority of the businesses are based (and harvest their seaweeds) in Scotland and near Islands, with a couple of businesses set up in Wales and the south west coast, one business in Northern Ireland (Irish Seaweeds) and one in Essex (Neo Argo Ltd). The same report identified eleven UK businesses using non-UK (or non-specified) seaweeds. Of these, four focused on cosmetics production, three on chemical production from seaweeds (e.g. hydrocolloids), two on animal feed/supplements and two on human food. Those relevant companies for the Client's interests in Bioenergy and Biotechnology are summarised in the table below. This has been augmented with companies identified by IPP's own searching. Sources of seaweed (by country) are stated where known.

The worldwide supplier landscape of hydrocolloids is concentrated into a few major players across Europe and the U.S., but is more scattered across the Asia-Pacific region. The competition in the hydrocolloid market is intense, with a few large players such as FMC Corp., DuPont, Archer Daniels Midland Co., Arthur Branwell & Co., Ashland Inc., Cargill Inc., CP Kelco, Darling Ingredients Inc., Ingredion Inc. and Tate & Lyle Plc. Hydrocolloid supplies come from plants, animals and microbes, as well as seaweed extracts. The companies included in the list below have been selected as being the most relevant hydrocolloid suppliers for the Client, i.e., where they supply seaweed-derived hydrocolloids and source seaweed from third parties.

Most seaweed bioenergy companies use microalgae, which is a very different process to macroalgae. No macroalgae bioenergy companies were identified – most work in this area is still in the academic/research phase. For example, the Centre for Process Innovation, Newcastle University, the Scottish association for Marine Science, Queen's University Belfast and CEFAS have been awarded a grant from Innovate UK to look at the production of bio-methane from seaweed by anaerobic digestion ("SeaGas" Project). The University of Birmingham is also looking at technologies to capture carbon dioxide from the ocean in large-scale offshore seaweed farms, employing high-rate novel anaerobic digestion processes to convert that carbon to methane gas to be injected into the UKs gas grids. As a result, in consultation and agreement with the Client, a decision was taken to halt our primary research efforts in the bioenergy market, and focus our approaches to companies on the

[15] Netalgae (2012) *Seaweed Industry in Europe*

[16] https://www.farminguk.com/News/Trial-to-start-UK-s-first-seaweed-farm-commences_46259.html

biotechnology/biorefining market, as it was felt contacting microalgae companies would be of limited benefit at this time.

5.5.1 ACADEMIC & RESEARCH CONSORTIA

Many of the research programmes identifies in the table below have recently ended, though the research networks and infrastructure are still active and can be found through the project websites. There may be opportunities for GreenSeas to become involved in other collaborative research consortia in the future, if this remains an area of high interest for EU, Innovate UK and other funders.

Name	Funding	Area	Notes
EnAlgae	INTERREG IVB North West Europe	Bioenergy	To develop sustainable technologies for algal production, bioenergy and greenhouse gas mitigation, from pilot facilities to products and services. Development of 9 pilot-scale farms across 7 EU states.
At~Sea	EU FP7 Programme	Cultivation	To develop and advance technical textiles for demonstrating technical and economic feasibility of off shore cultivation of seaweeds.
BioMara	INTERREG IVA / Highlands and Islands Enterprise / The Crown Estate / The Scottish Government / DETI / DCENR	Bioenergy	To demonstrate the feasibility and viability of producing third generation biofuels from marine biomass. Joint UK and Irish project. Aim to engage with wider community.
Netalgae	Atlantic Area Transitional Programme / Innovation network / European Regional Development Fund	Multiple	To create a European network of stakeholders within the seaweed sector. Establish best practice model and policies for sustainable utilization of seaweed resources. Baseline study of national algae industries. Develop EU algal industry database.
SeaGas	InnovateUK	Bioenergy	To develop a process using seaweeds for generation of sustainable energy by anaerobic digestion. To investigate storage of seaweeds, AD process development, economic modelling, environmental and social impact assessment and supply chain.
MacroFuel	EU H2020	Bioenergy	To produce advance biofuels from seaweeds (i.e. ethanol, butanol, furanics and biogas). Develop rotating scheme for seaweed cultivation, improve pre-treatment and storage seaweeds, develop novel fermenting organisms, develop thermochemical conversion, perform sustainability and risk assessment of seaweed biofuel chain.
MacroBioCrude	EPSRC	Bioenergy	To establish an integrated supply and processing pipeline for the sustainable manufacture of liquid hydrocarbon fuels from seaweeds (high energy density liquid transport fuels).
MacroBiotech	Nordic Atlantic Cooperation	Cultivation	The main purpose of the project is to demonstrate the technical and commercial

Name	Funding	Area	Notes
			viability of the MACR concept for cultivating macroalgae in the open ocean. A budget of 2.5 million DKK.
Scottish Association For Marine Science (SAMS)	Scotland	Multiple	The first commercial-scale UK seaweed farm
SEAFARM	Sweden	Multiple	The overarching goal of this project is to develop a sustainable system for the use of seaweeds as a renewable resource in a future, biobased Swedish society. The transdisciplinary research approach includes techniques for cultivating seaweeds to be used as raw material in a biorefinery for the production of food, feed, biobased materials and bioenergy.
Seaweed Biorefinery	Netherlands	Bioenergy	Seaweed offers numerous possibilities for production of renewable chemicals and energy carriers for a future "bio-based economy". It is highly suited as a raw material for co-production of chemicals, biofuels and energy via the biorefinery approach. In this project suitable and efficient biorefinery strategies and concepts are developed for seaweed biomass.
MACRO CASCADE	EU	Multiple	The main objective of the project is to prove the concept of the cascading marine macroalgal biorefinery. This is a production platform that covers the whole technological value chain for processing sustainable cultivated macroalgae biomass – also known as seaweed - to highly processed value added products.

5.5.2 COMMERCIAL

Name	Location	Area	Seaweed Supply	Comments
Harvesting & Biotech Companies				
Marine Biopolymers	Ayr	Chemicals (alginates)	UK	Based in Ayr, extracting alginates from Scottish seaweeds but planning to extract high value components from seaweed for food, and pharmaceuticals, (e.g. improved alginates) but also industrial applications such as natural polymers.
Hebridean Seaweed Company	Stornoway	Harvesting & processing	UK	Uses services of manual harvesters in the Western Isles; have their own mechanical (Canadian) harvester. Aim to cut up to 6,000 tonnes/year.[4]

Name	Location	Area	Seaweed Supply	Comments
Neo Argo Ltd	Essex	Aquaculture products	UK	Based in Essex – are using macroalgae to filter out microalgae in ecologically sensitive areas.
Uist Asco	Isle of North Uist	Harvesting & processing	UK	Process and dries Ascophyllum nodosum for various uses. Subsidiary of Arcadian Seaplants (May 2017)
Arramara Teoranta	Ireland	Harvesting & processing	Ireland	Process and dries Ascophyllum nodosum for various uses. Subsidiary of Arcadian Seaplants
FMC Biopolymer	Girvan, Scotland	Alginates	Iceland/Norway	Large American firm who took over ISP in 2009, resulting in the Girvan factory becoming a blending plant rather than extract production (now in Norway). Sourcing is from Iceland via Norway.
Shropshire Seaweed	Shropshire	Fertilizers and cleaning products	Ireland	Organic plant feed (liquid kelp extract) Ascophyllum nodosum from Ireland, sold through Amazon, and small independent traders.
Cybercolloids	Ireland	Contract research		Conducts research/analysis on hydrocolloid process implementation but not only from seaweeds. Clients worldwide
DuPont	Worldwide	Hydrocolloids		
Ocean Rainforest	Faroe Islands	Harvesting & processing	Faroe Islands	Production of marine biomass from macroalgae in open ocean cultivation installations and aims to become a leading supplier of sustainable cultivated macro algae in open ocean environments for food, feed, cosmetic, pharmaceutical, nutraceutical and energy products. They are developing a method for cultivating seaweeds on the open ocean - thus moving away from a hunter-gathering style of procurement and into true aquaculture.
Bloom	USA	Foams		Producing a foam from algal blooms.
Healan	York	Agar		Independent gelatine supplier
E & O labs	Scotland	Agar	USA/China	Lab products including agar in petri dishes
Commercial Extract Companies				
Cargill	Worldwide	Hydrocolloids		Cargill offers one of the widest ranges of commercially available carrageenans, employing proven production processes and using a large variety of different types of red seaweeds (Rhodophyceae) from the Gigartinales group.
Biostadt India Limited	India	Seaweed extracts		
Acadian Seaplants Limited	Canada	Multiple		Acadian Seaplants Ltd., manufacturers of kelp, seaweed and other macroalgae products, human health supplements, sea vegetables, and crop health

Name	Location	Area	Seaweed Supply	Comments
Gelymar	Chile	Hydrocolloids		Gelymar is a company that produces and commercializes hydrocolloids, specialized in offering texturizing solutions for Food, Personal Care and Pharmaceutical
BrandT	USA	Fertilisers		
Seasol	Australia	Fertilisers		Australia's top selling liquid seaweed, and PowerFeed - dynamic fish fertilizer and concentrated liquid composts.
CP Kelco	USA	Fertilisers		GENU® carrageenans have established their position within the food, household and personal care industries as uniform gelling and texturizing agents of high quality. CP Kelco is one of the leading carrageenan producers in the world.
Chase Organics GB Limited	UK	Fertilisers		Seaweed extract and organic growing specialists
Indigrow Ltd.	UK	Fertilisers		Indigrow's Compass brand comprises a unique range of molecular seaweed and carbohydrate extract products. These seaweed products are produced using hand harvested ascophyllum nodosum, grown at a renewable, sustainable and environmentally friendly source.
Travena Ltd.	UK	Fertilisers		UK based suppliers of organic fertiliser and pond cleaner, using seaweed extract
Skipping Rocks Lab	UK	Bio plastics		First product, Ooho, recently launched. The spherical flexible packaging can also be used for other liquids including water, soft drinks, spirits and cosmetics, and the proprietary material is cheaper than plastic
PRAG Ltd	Wales	Fertilisers		
Cosmetics				
Seaweed Organics	Argyll	Cosmetics	Scotland	Harvested from Outer and Inner Hebrides and Shetlands Isles and products made in workshop kitchen in Argyll.
Faith in Nature	Manchester	Cosmetics		Manufacture in Bury. Sell to Holland & Barret across the UK, and Oxfam stores. No indication that seaweed is sourced from UK.
REN Skincare	UK	Cosmetics		Not all products are seaweed specific. Sell to dept. stores, pharmacies and Spas in over 50 countries
Base Formula	Melton Mowbray	Cosmetics		Importers, exporters and analysers of essential oils and absolutes.
Bentley Organic	UK	Cosmetics		Manufacture in England. Sell a range of cosmetics particularly soaps, including with seaweed. Available through Ocado and others, - around 30 online sellers.
Consultancy				

Name	Location	Area	Seaweed Supply	Comments
Eunomia	UK	Consultancy		Have contributed to the SeaGas project, a study investigating the potential for using seaweed in anaerobic digestion for the Centre for Process Innovation.

5.5.3 COMPETITOR MODELS

The business models of the operations which are most similar to GreenSeas are discussed in more detail below.

OCEAN RAINFOREST

Ocean Rainforest is a limited company located in the Faroe Islands engaged in the production of marine biomass from macroalgae in open ocean cultivation installations. It was formed on October 10 2007. In 2009 Ocean Rainforest obtained the licence for pilot testing close to a salmon farming operation. They were project coordinators for the MacroBiotech project (2012-2014). They now have 13.500 meter of seaweed seed lines in the Faroe Islands and aim to become a leading supplier of sustainable cultivated macro algae in open ocean environments.

ARRAMARA TEORANTA

Arramara's production facility is based in Kilkieran, Connemara, Co.Galway. Arramara harvest one type of seaweed (Ascophyllum nodosum) and have a processing plant to dry this. They sell the dried seaweed in a B2B model to a range of industries across the world. The seaweed is milled into various particle sizes depending on the various applications.

In 2013, Arramara Teoranta became a subsidiary of Arcadian Seaplants (Canada), a globally recognised industry leader in the processing of seaweed-based products for food, biochemical, agricultural and agri-chemical markets worldwide and in the cultivation and processing of unique seaweeds for Asian and global food markets.

HEBRIDEAN SEAWEED COMPANY

Hebridean Seaweed Company Limited is one of the largest industrial seaweed processors in Great Britain. The company manufactures seaweed products for use in the animal feed supplement, soil enhancement, alginate and nutraceutical sectors.

6 INDUSTRY FEEDBACK

FOR CONFIDENTIALITY REASONS THE INDUSTRY FEEDBACK SECTION HAS BEEN REMOVED FROM THIS DOCUMENT.

7 OPPORTUNITY ANALYSIS

7.1 FARMING AND PRODUCTION: DEVELOPMENT REQUIREMENTS

There are two essential requirements of the Client for entry into the macroalgae production market:

1. Seaweed farm with macroalgae species based on the end-products chosen as target markets for GreenSeas, for instance brown seaweed for alginate, such as Ascophyllum nodosum or Laminaria hyperborean (lower value), or Laminaria (higher value), or red seaweed for agar, such as Gelidium.
2. Processing facilities to harvest, dry and mill the seaweed for sale to industry.

From the industry feedback we have received so far, it may also be important for the Client to produce their own extracts, given the lack of current UK supply and the interest of extract-using companies in understanding the origin of their material. This may also allow the company to retain more of the value of the higher priced extract products:

3. Extract-processing facilities to allow the Client to produce their own high-value extracts

IPP understands that the Client has commissioned a separate report of the opportunities for macroalgae production in the food industry, and that food and also bioremediation will be the initial focus of GreenSeas' activities. The developments required for biotech applications may be different to those required for food and bioremediation. The Client is also interested in performing a technical feasibility study for their seaweed processing capabilities, which we believe would be valuable in assessing the viability of producing high-value extracts.

7.2 PRIORITY NON-FOOD OPPORTUNITIES

Our research and the feedback suggests that the two potential longer-term, non-food opportunities for GreenSeas are:

1. To supply dried, processed seaweed at scale to industry users. This is a broad B2B model which allows GreenSeas to target a range of industries, though there are well-established competitors so the species of seaweed selected by GreenSeas should be based on where there is unmet need in Europe, particularly for smaller UK companies initially.
2. To supply seaweed extracts to industry users. The company should again focus on Europe as its target market and identify extracts where there is market need but little European supply (such as alginates).

These routes are not mutually exclusive – indeed, it is difficult to envisage the second option without the first operation already in place. In part the decision of which route(s) will create the most impact will be driven by the feasibility of running (or accessing) both a seaweed processing (i.e. drying and milling) facility and a chemical extraction facility. The former is the main priority for GreenSeas' operations since its focus is on seaweed farming. It should be stressed that there are few companies who specialise in both steps of this supply chain – most either harvest and dry seaweed, or have a supply of seaweed from a 3rd party which they use to produce extracts. There is little research or

industrial activity in bioenergy applications from macroalgae, and any applications of this technology are years from implementation. IPP recommends that the Client consider branching into bioenergy only when their current operation is up and running at scale. There are likely to be opportunities to participate in consortia bioenergy R&D projects once operations are up and running to mitigate against the risks and costs associated with this embryonic industry.

The seaweed biotech industry is a fairly collaborative, particularly between geographically relevant organisations (i.e. Europe) and companies across the supply chain (harvesting, processing and extract producers) are open to collaboration/partnering. Summary details of Innovate UK grants awarded to companies farming or deriving high value products from seaweeds are provided in Appendix 9.2.

8 CONCLUSIONS & RECOMMENDATIONS

The table below summarises our analysis of the GreenSeas position and opportunities:

STRENGTHS	WEAKNESSES
• Few other commercial macroalgae farms in Europe • Unmet demand for UK and European supply of seaweed and derived products • Growing industry demand for seaweed and seaweed-derived products • Growing consumer awareness and acceptance of seaweed and associated natural products • New and evolving technologies emerging based on macroalgae products • Strong academic position for seaweed research and collaboration in the UK	• Bioenergy market at a very early stage and not a currently realistic commercial opportunity • Well-established, competing seaweed suppliers (using wild harvest and farmed supplies) • A lot of further capability development required for both biotech and bioenergy applications • Macroalgae farming is technically challenging – few other companies specialise in both harvesting/processing and high-value extraction
OPPORTUNITIES	**THREATS**
• UK-based macroalgae farming operation likely to attract industry interest • Collaborative European industry across the supply chain • Interest in collaboration expressed by companies contacted, including by subsidiary of a key industry player • Government and industry support for alternative fuel sources	• Seaweed extracts from Asia are currently dominant due to low price, which may be difficult to compete with

Overall, the opportunity for a commercial macroalgae farm in the UK shows promise in biotech applications. There is industry willingness among smaller, national companies to use a more local seaweed supplier, particularly for high-value extracts such as alginates. However, it may be difficult to compete on price with well-established Asian suppliers. The species of seaweed targeted by the Client should be selected based on where there is demand in Europe (the UK in particular) but which is provided from Asia. The species of seaweed is also an important consideration if GreenSeas opt to focus on the production of high-value extracts such as alginates. The quality of the extract produced, and the price that can be charged, is variable depending on the type of seaweed used.

Lastly, one other avenue not analysed further in this report, but potentially worth exploring as a business model for GreenSeas, is the cooperative approach, a model that has found adoption in the US by an ocean farmer and fisherman-run organisation that uses a sustainable, open-source polyculture vertical farming system, growing a mix of seaweeds and shellfish that require zero input. Crops are used as food, fertilizer, animal feed and more.

9 APPENDIX – INNOVATE UK AWARDS

Title	Date	Abstract	Project grant	Lead participant (and region)	Other participants
Seaweed as a Solution for Sustainable Economic and Environmental Development (S3EED)	01/05/14 - 30/11/14	Seaweed is healthy, nutritious and very tasty. Worldwide, seaweed for human consumption is the largest aquaculture industry. But here in the UK we are only just waking up to seaweed's culinary potential. However, the seaweed industry in the UK is growing and now requires more seaweed than can be harvested from the wild. And so there is a need to start farming it. This project, Seaweed as a Sustainable Solution for Economic and Environmental Development (S3EED), will develop the technology to grow two species of delicious seaweed in the cool, clear waters that surround the UK.	£266,174	The Scottish association for Marine Science (Highlands and Islands)	Otter Ferry Seafish Mara Seaweed
SeaGas : Production of bio-methane from seaweed by Anaerobic Digestion (AD)	01/07/15 - 30/06/18	This project will develop a process which uses seaweed for the generation of sustainable energy by anaerobic digestion (AD). Currently, farmers, food processors and industry use AD to generate bio-methane from wastes, to reduce energy costs or provide income. As waste supplies can be variable and AD is a continuous process, food crops like maize and beets are used to supplement waste. Seaweed has the potential to replace these food crops, which use land and water which could otherwise be used for human food production. The UK has extensive coastal waters and internationally recognised academic excellence in seaweed, its growth requirements and environmental considerations. This project brings together expertise in AD process development, economic modelling, environmental and social impact assessment and the supply chain - from seabed access for seaweed farming through to biogas injection into the national grid.	£1,053,790	The Centre for Process Innovation (North East)	Newcastle University The Scottish association for Marine Science Queen's University Belfast CEFAS

Title	Date	Abstract	Project grant	Lead participant (and region)	Other participants
Seaweed trial	01/01/13 - 31/03/13	Seaspice is a niche brand selling high value seaweed products. We lead on taste and innovationto exploit the nutritional and health benefits of seaweed, which are only just beginning to be understood. Our problem is a sustainable supply of high quality seaweed- so we want to work out how to recreate the essential conditions of the seashore to farm seaweed. This would be a majoir breakthrough for our business and has the potnetial to kick-start an imnportant and valuable industry for the UK	£5,000	Mara Seaweed (East of Scotland)	
Seaweed Seed Treatment	01/08/15 - 31/01/16	Seaweed has been used for several centuries to improve crop production through its composition containing minerals, amino acids and stimulants. Through innovation we have prepared a new process that extracts a functional fraction of the seaweed which is applied in a concentrate on the plants able to improve yield. The benefits are seen through plant health and quality. The proposed work will provide an understanding on the mode of action to optimise the formulated product further before launching.	£5,000	Uist Asco (West of Scotland)	
The effect of seaweed extracts on grass seed establishment and growth	01/08/15 - 31/01/16	"Armstrong Richardson are agricultural merchants based in North Yorkshire, supplying farm animal feeds, fertilizers and grass seeds. We have identified a market demand for a UK-sourced supply of naturally-derived fertilisers/ bio-stimulants and are keen to explore the use of seaweed extracts as seed treatment, in the first instance. If successful, the exploitation of the results will enable us to develop novel 'greener' growth promoter products from UK-source, ensuring we efficiently respond to the market demand, remain competitive in the global market, and generate revenues and growth in the UK	£5,000	Armstrong Richardson & Co (Yorkshire and Humberside)	

Title	Date	Abstract	Project grant	Lead participant (and region)	Other participants
Natural Antimicrobial Compounds from Seaweed	01/11/15 - 31/10/16	Biocides deter or exert a controlling effect on harmful organisms, bacteria and fungi. The use of biocides, in disinfectants and antiseptics, is a key component for many effective programmes in the prevention and control of healthcare-associated infections. However serious concerns about the resistance of bacterial pathogens to biocides has been growing for a number of years. Hence there is an increasing demand for different biocides to be found. This is rather difficult due to the majority of current biocides (99.5%) being chemically derived and containing halogen, metallic and phenolic compounds. As a result, the biocides industry has been severely challenged on the lack of sustainability and levels of toxicity. Byotrol proposes to overcome these growing concerns and limitations by extracting and formulating biocides from the alternative, renewable and natural resource of seaweed.	£94,474	Byotrol PLC (North West)	
Natural Antimicrobial Compounds from Seaweed	01/12/14 - 31/03/15	Biocides deter or exert a controlling effect on harmful organisms, bacteria and fungi. The use of biocides, in disinfectants and antiseptics, is a key component for many effective programmes in the prevention and control of healthcare-associated infections. However serious concerns about the resistance of bacterial pathogens to biocides has been growing for a number of years. Hence there is an increasing demand for different biocides to be found. This is rather difficult due to the majority of current biocides (99.5%) being chemically derived and containing halogen, metallic and phenolic compounds. As a result, the biocides industry has been severely challenged on the lack of sustainability and levels of toxicity. Byotrol proposes to overcome these growing concerns and limitations by extracting and formulating biocides from the alternative, renewable and natural resource of seaweed.	£23,363	Byotrol PLC (North West)	
Bioactive nutraceuticals from seaweed (NUTRALGA)	01/11/12 - 31/03/13		£5,000	Keracol (Yorkshire and Humberside)	

Title	Date	Abstract	Project grant	Lead participant (and region)	Other participants
Seaweed Extract Analysis	01/08/14 - 31/01/15	External expertise will be used to define and confirm the levels of key components in our seaweed extracts to ensure that they meet the requirements of the new end-users. The important components for the new markets are the potentially bioactive fucoidans, fucoxanthins and polyphenols but also the mineral composition. Information on these components will also be useful to cross-compare our extracts against extracts from other sources.	£5,000	Hebridean Seaweed Company (Highlands and Islands)	
Seaweed in paints	01/11/15 - 30/04/16	investigate the uses of alginates in a manufacturing industry	£5,000	Isle of Skye Paint Company (Highlands and Islands)	
Seaweed Project	01/08/15 - 31/01/16	Bridgwater College	£5,000	Anode Feeds (South West)	
Seaweed Elan II	01/08/14 - 31/01/15	External expertise is required to advise on marketing strategy for the development of an algal biofertiliser technology platform that appropriately meets the market needs of the horticultural and agricultural sectors within the EU. A technology roadmap will be set out and market opportunities within the EU identified and priotized. A specific product type will be selected for initial development. This undertaking will require a combination of end user, market and technology insight.	£5,000	Elan Produce (West Midlands)	
Feasibility of High Value Polysaccharide Extraction from UK Seaweeds	01/05/11 - 31/07/11	Awaiting Public Summary	£24,675	Marine Biopolymers (West of Scotland)	
The University of Birmingham and Blue Sky Bio Limited	01/05/15 - 31/10/17	To capture carbon dioxide from the ocean in large-scale offshore seaweed farms, employing high-rate novel anaerobic digestion processes to convert that carbon to methane gas to be injected into the UKs gas grids, increasing our energy security.	£131,258	University of Birmingham (West Midlands)	