

# ALGAL RESEARCH IN THE UK

## A SCOPING STUDY FOR BBSRC

### SUMMARY AND RECOMMENDATIONS

#### BBSRC Statement of Intent

“BBSRC wishes to understand whether and, if yes, how it should address fundamental research into the biology of algae in the context of a feedstock for energy and other related products. BBSRC recognises that the routes to these products may well be long term. This is an exploratory exercise by BBSRC – there is no commitment to follow-up funding.”

#### Disclaimer

The report aims at establishing where in the UK algal research is being carried out, and what topics are being investigated. The information presented is based on the responses received from participants in a questionnaire, and on stakeholder engagement. **The scope of the report did not allow for quality control of the stakeholder responses, and hence no qualitative judgement is made of the participants.**

While care has been taken to be fully inclusive in the report, the limits of scope and time mean that there will without doubt be algal players who unintentionally have been overlooked, and information may have been misinterpreted. The author would appreciate it if she could be notified of any omissions or corrections needed, so that the correct information can be passed on to BBSRC.

#### OVERVIEW

Over recent years, algae<sup>1</sup> have received much attention in the media on an international level, primarily as a potential source of renewable transportation fuels. They have been highlighted as a feedstock that is not tainted with the ethical dilemmas of current, food-based biofuels: they do not require arable land; need not compete for freshwater but can grow in marine, brackish or nutrient-rich waste water; and in addition can be used to scrub CO<sub>2</sub> and NO<sub>x</sub> from flue gasses. Furthermore, growth rates tend to be considerably faster compared to land plants (doubling times as little as 8 hours), oil yields per unit area for some species are more than 20x higher than *e.g.* for oil seed rape<sup>2</sup>, and as a group their tremendous metabolic diversity offers a wide spectrum of potential fuel molecules.

However, the potential of this immensely diverse group of organisms to address major global challenges extends far beyond their use as an energy feedstock. Applications for food, animal feed, materials (*e.g.* replacements for petrochemicals), speciality products and in bioremediation services are in several cases more advanced than fuel applications, and often do not require the same scale of production. As a consequence, they are more attractive for adoption in the UK where space is limited. Importantly, algae offer great potential for developing novel biotechnological applications, to underpin building a bio-based economy.

---

<sup>1</sup> Following the definition of RE Lee (Phycology, 2008, Cambridge University Press, p.3), the term ‘algae’ in this report is used to refer to both macro- and microalgae, with the latter including prokaryotic algae (cyanobacteria). Purple photosynthetic bacteria, which are anoxygenic, are not included.

<sup>2</sup> Scott *et al.* (2010) *Current Opinion in Biotechnology*, **21**, 277-286

In the light of the global interest in algae, BBSRC commissioned this study because it wishes to understand whether it should address fundamental research into the biology of algae in the context of a feedstock for energy and other products, and if so, how.

This study is split into two parts; in Part I, it takes stock of **current and past algal activity in the UK** (Chapter 1), gives an overview of **algal interests globally** (Chapter 2), and reviews **markets for algal products and services** (Chapter 3).

Part II builds on this information to analyse how the UK can best capitalise on its strengths in the light of current and emerging opportunities for algal R&D, and in the context of international competition. It firstly reviews **potential opportunities for algal R&D to progress in plant science and biotechnology** in general, with an emphasis on underpinning food, energy and material security, and progressing biotechnology (Chapter 4). It then assesses the **strengths of the UK research capability on the global algae stage** (Chapter 5), and moves on to analyse **gaps in algal research value chains** in the UK (Chapter 6). Levels of risk, reward and importance of **areas of RD&D required to promote the development of an algal economy** are assessed in Chapter 7. Finally, in Chapter 8, the outcomes of this study are compared to a previous DECC report from 2009, entitled 'Assessing the Potential for Algae in the UK'<sup>3</sup>; progress against the recommendations of this report are considered, and further **recommendations** are made.

## PART I: TAKING STOCK

### Chapter 1 - Current and Past Algal Activity in the UK

The UK has a wealth of algal experience in the academic arena as well as in industry, relevant to the use of algae both as an energy feedstock and in biotechnological and other higher value applications. Great benefits could be derived from integrating this expertise to a greater extent.

#### Algal Expertise in Academia

##### *Historic perspective (Section 1.1)*

Pro- and eukaryotic algae have been – and continue to be – studied by a distinguished cohort of UK scientists. A considerable proportion of their work has led to the elucidation of key metabolic pathways and physiological functions with high relevance for both plant and animal biology, and has contributed to the foundations of algal biochemistry, molecular biology, physiology, phylogeny, taxonomy and ecology. Furthermore, the UK has a strong history of excellence in maintaining and expanding algal culture collections, and the foundations for several now globally-used algal engineering solutions were laid by UK academics.

*R&D on algae carried out in the UK over the last century has brought bioscience forward in general, and has laid strong foundations that both algal research and several industrial applications are now building on world-wide.*

##### *Current Academic Expertise (Section 1.2)*

To obtain an indicative<sup>4</sup> profile of the current algal research community in the UK, a list of researchers was collated from discussions with stakeholders, and amplified by searching the online databases of funding bodies for grants awarded that contained relevant key words. In this way, 322 UK academics were identified as

---

<sup>3</sup> available from [www.nnfcc.co.uk/tools/assessing-the-potential-for-algae-in-the-uk](http://www.nnfcc.co.uk/tools/assessing-the-potential-for-algae-in-the-uk)

<sup>4</sup> The report does not claim to be inclusive, and makes no judgement on the quality of the research expertise collated in this chapter.

contributing to algal R&D<sup>5</sup>. To obtain an up-to-date picture of the research expertise and interests of the identified researchers, a questionnaire was designed jointly with the Director of the NERC-TSB Algal Bioenergy Special Interest Group (AB-SIG) and sent to both the collated list and to the mailing list of the British Phycological Society. Of those who responded (170), 3/4 indicated that algae were at the core of their research interest, and the remaining 1/4 that algae were a peripheral interest. Approximately 1/3 had an interest in macroalgae, 2/3 in microalgae, with a small overlap. More researchers were interested in marine than in freshwater algae, and equal numbers pursued fundamental and applied research. Of the given list of research interests, environmental issues were chosen most frequently, followed by bioenergy, algal communities and algal productivity. Bioprospecting and cosmeceuticals had the smallest number of interested researchers.

Based on the data collated from the questionnaires, the UK has particular strength in **biological** and **ecological research**. Of the biological disciplines and research areas, **photosynthesis** research, **molecular biology** and **physiology** were most widespread, followed by **biochemistry**, **taxonomy**, **metabolism**, **phytoplankton** research and **biotechnology**. Expertise in the **marine environment** appears to be more widespread than in fresh water. There is also considerable expertise in the applied areas of biomass / biofuel **production** and chemical and process **engineering**.

The extensive sample of the algal research expertise provided in Chapter 1 highlights the great wealth and breadth of capability relevant to algal research which is currently present in the UK. Some initiatives already exist which bring several of the groups and institutions together (*c.f.* Section 1.2.3), and participants in these initiatives have commented on the immense benefit they have derived from exchange and collaboration with other groups. Overall, however, the community describes itself as disjointed, which can in part be attributed to a lack of coherence in existing funding streams and absence of strategic leadership<sup>6</sup>. Step changes could be expected if the expertise of this community, whose excellent research overall has been limited in impact by lack of integration, were to come together to apply their experience under the umbrella of a strategic framework. This would enable the UK to capitalise on the strengths of the algal research community, to compete strongly on the global stage and to address some of the key challenges which our society faces.

### UK Algal Industries (Section 1.3)

Over the past 30 years, the UK has produced a number of highly innovative algal companies whose work has driven the algal field forward on an international level, although they have not always been commercially successful. Currently, a small number of UK companies are well established on an international stage; these are either technology providers, or service the high value spectrum of algal products from established species and strains. There are early beginnings of an algal biotechnology industry, either through biorefining (e.g. of macroalgal biomass), or by developing microalgae as a customised expression platform. Hardly any commercial activity exists in downstream processing.

Looking ahead to emerging opportunities for new industrial activities, considerable potential exists on the biological side to build on the academic expertise in e.g. synthetic biology. Industrial biotechnology solutions could and are being developed; these could then be commercialised through partnership with existing companies, or by forming university spin-outs. On the engineering side, the greatest potential for the UK currently lies in the development of integrated solutions for growth and processing, following the biorefining concept. Many academic groups and industrial technology providers exist whose expertise could be drawn on to further develop such integrated algal solutions, once feasibility had been confirmed and the sector had gained momentum.

---

<sup>5</sup> The methodology has clear weaknesses: Only the major funding bodies have public databases that can be searched, hence researchers funded through smaller foundations, or through industry, would not have been captured unless they were known to the group of stakeholders with whom the list was cross-checked. False positives were also observed. Despite the limitations, the results obtained with this methodology provide a useful indication of the variety of algal expertise in the UK.

<sup>6</sup> *c.f.* key outcomes of DECC report ([www.nnfcc.co.uk/tools/assessing-the-potential-for-algae-in-the-uk](http://www.nnfcc.co.uk/tools/assessing-the-potential-for-algae-in-the-uk); p.3)

## Chapter 2 – International Key Players and Major Objectives

To assess its competitiveness and potential impact, the algal R&D capability in the UK needs to be put into the context of global activity on algae. International interests are developing rapidly and are in constant flux; overall the biggest players are the US (who pursue algae both from the point of view of energy security and for biotechnological solutions), and the BRIC countries. The latter are investing heavily into algal R&D and are rapidly catching up with the longer-established centres of expertise in Israel, Australia and the EU.

Nations which have a long-established history of expertise for macroalgae – chiefly in applications for food, fertiliser, alginates, and pharmaceuticals – include China, Japan, the Philippines, Korea, Indonesia, Chile, and in Europe coastal countries such as France, the UK, Norway and Portugal. For microalgae, the US<sup>7</sup>, Australia, Israel, Japan, China, Taiwan and several EU countries have well established capabilities, again chiefly in high value applications such as nutraceuticals.

The more recent biofuels boom has had a large influence especially in the US and the BRIC countries; considerable funding has been invested there<sup>8</sup>. A significant number of companies make unrealistic claims about productivities and profits, which threaten the credibility of the field in general. The collapse of many new companies, including the high-profile MIT-spin-out GreenFuel Technologies Corporation in 2009, has led to more caution. Internationally the recognition is growing that the pursuit of algae for bioenergy only will make successful commercialisation very difficult; the general trend is towards integrative solutions that make use of the protein fraction for food and feed, as well as the oil fraction for fuel.

There is also an increasing trend to exploit algae as an industrial biotechnology platform; international leaders in this field are the US, Israel, and the EU, although BRIC countries are catching up rapidly.

Several Algal Centres focusing on the scale-up of algal technologies have been established in the EU and internationally, providing collaborative opportunities between academia and industry. In the EU, a large number of cross-national projects are investigating a wide spectrum of algal issues, many with UK participation; these projects offer further opportunities for UK academics and industries to engage in follow-up R&D activities.

To give stakeholders up-to-date information about the rapidly evolving landscape of international algal players and interests, several bodies and initiatives have sought to collate and distribute information on algal expertise world-wide. These include the EU programme AquaFUELS<sup>9</sup>, the European Algal Biomass Association<sup>10</sup>, the FAO Aquatic Biofuels Working Group<sup>11</sup>, the India-based information resource Oilgae<sup>12</sup> and the US-based Algae Industry Magazine<sup>13</sup>.

---

<sup>7</sup> with its Aquatic Species Programme (the close-out report of which is available at [www.nrel.gov/docs/legosti/fy98/24190.pdf](http://www.nrel.gov/docs/legosti/fy98/24190.pdf)), as well as pioneering nutraceutical companies

<sup>8</sup> Examples of recent substantial funding support include \$24 million awarded by the US Department of Energy in June 2010 to three research consortia to address the existing difficulties in the commercialisation of algal-based biofuels. Source: [www1.eere.energy.gov/biomass/news\\_detail.html?news\\_id=16122](http://www1.eere.energy.gov/biomass/news_detail.html?news_id=16122)

<sup>9</sup> The final version of the AquaFUELS “Report on Main Stakeholders” is available at [www.eaba-association.eu/dl\\_misc/indexd1.3.html](http://www.eaba-association.eu/dl_misc/indexd1.3.html)

<sup>10</sup> The EABA is in a constant process of updating and expanding the AquaFUELS list, to deliver an “EABA Who’s Who Directory of Algae Stakeholders”

<sup>11</sup> [www.fao.org/bioenergy/aquaticbiofuels/aquaticbiofuels-home/jp/](http://www.fao.org/bioenergy/aquaticbiofuels/aquaticbiofuels-home/jp/)

<sup>12</sup> [www.oilgae.com](http://www.oilgae.com)

<sup>13</sup> Free daily email updates can be subscribed to via [www.algaeindustrymagazine.com](http://www.algaeindustrymagazine.com)

## Chapter 3 – Algal Products and Indicative Market Values

Algae can be cultivated to produce a wide range of end products. The market values for these products range from £100's per tonne for energy products to £1000's per gram for very high value products. In most cases products derived from algae need to break into established markets dominated by other, often petrochemical feedstocks, and compete with well-established supply chains (*e.g.* for fuels and plastics). Some product groups exist (such as hydrocolloids or feed for fish hatcheries) which can only be derived from algae, or where algal products have functional advantages over alternatives; there are examples of such products that are already established on the market, and it is very probable that more will be found.

Algal products can be classified into four categories based on monetary value:

1. Base commodities (high volume, low value)
2. Added value commodities (high volume, added value over energy)
3. Speciality products (low volume, high value)
4. 'Ceuticals' (very low volume, very high value)

In addition, algae can be used to perform bioremediation services.

Currently the only algal products on the general market are speciality products and some 'ceuticals'. For microalgae, these include pigments, omega-3 and -6 fatty acids, vitamins and whole algae as speciality food / feed items and for cosmetics; for macroalgae they encompass speciality food / feed, fertilisers and hydrocolloids. Costs of existing products may be lowered by adopting integrated biorefining approaches, coupled where possible with bioremediation services. Base commodities such as bioenergy and bulk feed are not financially viable as yet, and production pathways for algal platform chemicals still need to be developed.

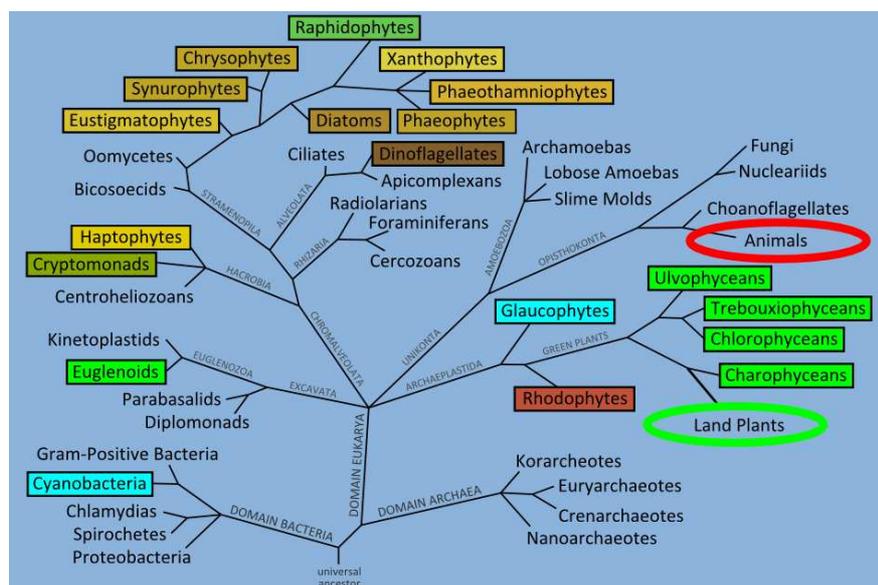
At this time an area with particular development potential for the UK appears to be the exploitation of high value chemicals for cosmeceuticals and nutraceuticals markets in the context of industrial biotechnology. Other areas of significance include generating IP *e.g.* for liquid biofuels (to be applied internationally), replacing fishmeal in animal feed, and developing integrated growth systems with anaerobic digestion and aquaculture. Given adequate support, algae have the potential to become a substantial driver in the development of a bio-based economy in the UK.

## PART II: WHAT NEXT

### Chapter 4 - Potential Opportunities and Benefits of Algal R&D to Progress in Plant Science and Biotechnology

Evolution has led to immense diversity across all domains of life; a cornucopia that can be mined for bio-active molecules, enzymes, pathways and traits for potential biotechnological applications. In this diversity across all forms of life, both animals and land plants occupy a rather narrow phylogenetic space. Algae, however, are represented across almost the entire tree of life (Fig. E.1), and are found in any imaginable habitat – be it deserts, arctic ice, salt lakes or hot springs. Collectively they therefore provide a truly staggering richness of diversity – a resource that as yet has been little explored. If constructively supported algal R&D will unlock this resource and contribute to solving major challenges, such as security of food, materials and energy. It will also benefit the progress of biological and biotechnological disciplines in general.

Fig. E.1: Phylogenetic tree highlighting the diversity and distribution of algae (boxed groups; colours indicate the diversity of pigmentation) across the domains of life<sup>14</sup>. For comparison animals and land plants are encircled in red and green, respectively.



Algal genomes and metabolomes can be mined for useful traits<sup>15</sup>, such as tolerance to extremes of temperature, irradiation, drought and salinity; these can be introduced into other crops. Likewise, valuable algal metabolites (e.g. omega-3 and -6 fatty acids, vitamins, antioxidants, pigments, platform chemicals, precursors for plastics, pharmaceuticals) can either be expressed in algae and/or their expression pathways introduced into other systems.

The field of artificial photosynthesis and solar fuels draws heavily on the wide design spectrum of light harvesting solutions from pro- and eukaryotic algae. It is founded on the principles of nature, and uses them as starting points for biomimetic systems. This also includes solar H<sub>2</sub> production and CO<sub>2</sub> reduction. Furthermore, the diversity of algal light harvesting systems is the basis for engineering improved photosynthetic organisms that will use the entire visible spectrum.

In addition, algal R&D can inform aspects of health and animal science, such as diseases caused by defective cilia, and can further progress of fundamental science especially in the field of evolution.

One of the most promising areas, however, is the development of algae as a novel platform for industrial biotechnology. This would not only address several shortcomings of existing cell-based expression systems, but importantly has the potential to become a disruptive technology for plant sciences, *i.e.* a step to enable synthetic biology approaches to be established and used in other plants and crops. Advantages of algal expression platforms such as *Chlamydomonas reinhardtii* include

- fast growth and short life cycles
- ease and low cost of culturing
- compatibility with high-throughput screening
- high expression levels and solubility of metabolites and proteins
- choice of chloroplast-based (*i.e.* resembling prokaryotic) or nuclear (*i.e.* eukaryotic) expression
- potential to secrete products into the vacuole or the medium
- minimal interference with inserted expression pathways.

<sup>14</sup> adapted from <http://www.keweenawalgae.mtu.edu/>, with kind permission of Jason Oyadomari

<sup>15</sup> This is already being developed commercially through a partnership between Sapphire Energy Inc. and Monsanto Company, *c.f.* <http://monsanto.mediaroom.com/index.php?s=43&item=934>, and [www.nature.com/nbt/journal/v29/n6/pdf/nbt0611-473b.pdf](http://www.nature.com/nbt/journal/v29/n6/pdf/nbt0611-473b.pdf)

## Chapter 5 – Strength of UK Capability on the Global Algae Stage

As the results of the survey described in Chapter 1 have highlighted, academia in the UK has great expertise in the environmental and ecological sectors for both micro- and macroalgae, especially (but not exclusively) in the marine sector. This capability is shared by some European countries. The UK's ecological expertise is of great value and can help to combat algal diseases and predators, and capitalise on helpful symbioses. If this capability can be integrated into budding commercial activities, both nationally and internationally, it can both save costs and contribute to preventing ecological disasters in scale-up of algal growth.

The UK's expertise in life cycle analysis (LCA) is also of importance globally, since sound LCA is fundamental to any energy application, and highly advisable for other applications. The UK is well placed to build further capacity to satisfy growing global demand in this area (and also modelling in general, since these approaches – if supported by sound datasets – can replace expensive experiments, allow exploration of a multitude of possible scenarios and thereby accelerate progress).

The algal culture collections in the UK are internationally leading<sup>16</sup>; other important collections exist in e.g. Japan, the US, Germany and France. Redundancy here is essential, to avoid contamination or natural disasters in one collection wiping out access to important strains.

In terms of industrial activity, the UK has contributed to major breakthroughs in applied biology and engineering, which have now been adopted by international players<sup>17</sup>. Both academia and industry are actively involved in designing photo bio-reactors (PBRs) and integrated systems for producing algal biomass (on an international level, activity in the field of PBR design and biomass growth is particularly strong e.g. in Italy, Spain, Portugal, Germany, the US and Israel).

Fundamental biology is one of the UK's key strengths; major breakthroughs in photosynthesis research have been made in the UK, and a wealth of experience exists in taxonomy, physiology, metabolism, biochemistry and molecular biology of algae. This expertise is now increasingly being employed in a biotechnological context, with high relevance to underpinning a bio-based economy. The US, Israel and several European countries also have considerable activity in this area, and constitute serious competition to UK efforts. ***Nevertheless, the challenge posed by the world's need to turn from a petroleum to a bio-based economy is of such magnitude that parallel research approaches are needed to find solutions on acceptable timescales. This represents a window of opportunity for UK expertise.*** The high quality of the UK research base in this area, as well as creative approaches which are characteristic for UK-based scientific excellence, add considerably to the UK's competitiveness, and need to be fully made use of.

## Chapter 6 – Algae Research Value Chains in the UK

To increase the impact of algal expertise in the UK, it is important to connect together the various research elements that are needed to develop the outputs of fundamental research onwards into applications. In the UK context, it is helpful to differentiate between two overarching value chains for algal research:

1. fundamental research leading to the **development of novel high tech solutions and high value products employing algae**, with the end goal of building future generations of algal technology applications, and
2. **further improvement and optimisation of existing applications** in order to make them financially viable, more profitable and/or environmentally acceptable.

---

<sup>16</sup> [www.CCAP.ac.uk](http://www.CCAP.ac.uk); [www.mba.ac.uk/culturecollection.php](http://www.mba.ac.uk/culturecollection.php); [www.mba.ac.uk/culturecollection.php](http://www.mba.ac.uk/culturecollection.php); complemented by [www.nhm.ac.uk/research-curation/research/projects/algaevision/index.html](http://www.nhm.ac.uk/research-curation/research/projects/algaevision/index.html)

<sup>17</sup>The success of e.g. Martek Biosciences Corporation is based on a technology developed by the British company Celsys, now closed

Considerable expertise exists in the UK that can contribute to both of these value chains. Both in different ways – and with input from different kinds of fundamental research – have potential to underpin the development of a bio-based economy in the UK.

The first value chain requires intense, lab-based R&D (Technology Readiness Level (TRL) 1-4). This research tends to produce stand-alone end products (a patented process or physical product) which are often taken to higher TRL levels through spin-out companies from research institutes. Outputs include underpinning methods and technologies that can be patented and licensed, as well as novel products.

Bottlenecks for this value chain have included scarcity of dedicated funding support and of mechanisms by which researchers can interact with industry in a meaningful way. Such interaction would help to identify pathways of conducting world-class science; science which has outputs that are of high relevance to industry, and hence the potential to identify routes to commercialisation. Encouraging steps in this direction have been taken by the Synthetic Plant Products for Industry Network (SPPI-Net), who organised an Algal Synthetic Biology Workshop in London in March 2011<sup>18</sup>.

The second value chain is intimately connected to the scale-up of algal production and hence requires integrated multi-disciplinary work across a spectrum of science and engineering disciplines. Laboratory-based biological and biotechnological work is in most cases still essential; however, it has to be informed by the requirements imposed by the entire pipeline (since improvements in one area may introduce difficulties in another), and needs to develop integrative approaches underpinned by sound LCA and ecological assessments. Outputs are likely to be in the form of co-products and include: base commodities such as biomass for energy generation and bulk animal feed; high value products such as speciality feeds / foods, nutraceuticals and cosmeceuticals; and bioremediation services such as waste water clean-up and CO<sub>2</sub> / NO<sub>x</sub> scrubbing.

Bottlenecks for this value chain include a lack of trained personnel with a sound grasp of algal biology, ecology and engineering (this is a global problem<sup>19</sup>), and of solid data that can feed into modelling approaches (especially the all-important life cycle and sustainability analyses). A key gap is the provision of funding opportunities that encourage researchers to collaborate and develop synergies between their research activities. Such funding would best be delivered under the umbrella of a strategic research agenda which has been developed with the buy-in of the research community.

To address the bottlenecks in both value chains, it is recommended that BBSRC together with other Research Councils and funding bodies such as TSB, and in consultation with academia and industry, develop a joined-up strategy for algal value chains in the UK. This would need to be followed up with integrated funding<sup>20</sup> appropriate to the various bodies involved. A strategic approach to funding will ensure that the algal research strengths, which the UK undoubtedly possesses, will be counted on the international stage, and that the benefit of this expertise will be felt in the UK directly through underpinning the development of a national bio-based economy.

Strategic funding should include a cross-council Graduate Training Programme to build capacity in graduates and post-docs with a sound understanding of the biological, engineering and environmental challenges, the integrated solutions to which are so crucial for successful commercialisation of algal technologies. Another priority area should be the establishment of a peer-reviewed, open access database for information to feed into modelling studies and life cycle and sustainability analyses.

---

<sup>18</sup>A summary of the outcomes of this meeting is available at [www.sppi-net.org/downloads/AlgalSyntheticBiologyWorkshop0411.pdf](http://www.sppi-net.org/downloads/AlgalSyntheticBiologyWorkshop0411.pdf).

<sup>19</sup> Availability of trained personnel has been highlighted as the second-most critical issue for global algal industries in The Algal Industry Survey, Feb 2009 (p.7); available at [www.ascension-publishing.com/BIZ/algal-industry-survey.pdf](http://www.ascension-publishing.com/BIZ/algal-industry-survey.pdf)

<sup>20</sup>It needs to be stressed that strategic focus, albeit highly important, must not be to the detriment of funding algal blue skies research (which tends to produce the most innovative and ground-breaking solutions; a prominent example is Michael Faraday).

## Chapter 7 – Areas of RD&D Required to Promote the Development of an Algal Economy

Algae have considerable potential to contribute to a sustainable bio-based economy in the UK: through development of an industrial biotechnology platform which underpins food, energy and material security, and through integrated biorefining solutions for fuel, feed, (platform) chemicals and bioremediation services. Algae therefore have an important role to play in two of BBSRC's Priority Areas, Industrial Biotechnology & Bioenergy, and Food Security.

To establish the full extent of these opportunities, and to turn the potential into economic reality, considerable RD&D needs to be carried out. The risks and rewards associated with different aspects of the broad spectrum of RD&D topics vary considerably, as do their importance for progress of the overall field.

Regarding RD&D that will develop algae as a platform for industrial biotechnology, highest importance and reward at this stage are attributed to:

- further development of tool kits for algal synthetic biology
- expanding the evidence base that highlights the advantages of using algal systems.

Concerning RD&D that will further improve and optimise existing applications for energy, high value products and bioremediation services, highest levels of reward and importance are ascribed to:

- establishing test / pilot / demonstration sites for macro- and microalgal projects
- capacity building for multidisciplinary work
- achieving sustained growth of desired strains with stable desired characteristics
- optimisation of growth on medium derived from AD liquid digestate.

The INTERREG initiatives BioMara and EnAlgae described in Chapter 1<sup>21</sup> will contribute to addressing these issues, but a much larger coordinated effort across the UK is needed to fulfil the potential algae have to contribute to sustainable economic growth.

In the medium and long term, the outputs of the RD&D areas described above should converge in the concept of an integrated biorefinery, where algal biomass – dedicated crops and/or residual biomass after extraction of high value compounds from industrial biotechnology approaches – would be fractionated into its useful components. Theoretically these comprise

- protein for food or feed
- carbohydrates as feedstocks for biopolymers or bioalcohols
- lipids for food, feed, oleochemicals or biodiesel
- potentially metabolites for chemical applications.

Caveats include that only a subset of end uses will be appropriate for any given feedstock, and that all developments need to be underpinned by sound life cycle and sustainability analyses. With these in place, however, algae can be developed into a highly versatile branch of the bio-based economy.

---

<sup>21</sup>Section 1.2.3

## Chapter 8 – Conclusions and Recommendations

The UK has a substantial biological expertise to offer in the establishment of algae as significant contributor to a bio-based economy.

At the most fundamental level the study of algae has the potential to unlock solutions to many of the most pressing long term challenges that planet earth faces in the 21<sup>st</sup> Century. As we seek answers to more immediate issues this must not be overlooked; indeed it should be actively fostered as an essential and integrated element of algal R&D as outlined below.

Short and medium term issues should be addressed both through stand-alone high tech approaches to build algae as an industrial biotechnology platform, and by developing algal products and services. These are complemented by extensive associated ecological expertise that helps to understand and model the role of algae in *e.g.* climate change and develop them as bio-indicators for environmental impact.

### ***Progress since 2009***

This study follows on from a report<sup>22</sup> on the outcomes of an algal stakeholder meeting called by DECC and facilitated through NNFCC on 12 November 2009. The event aimed “to establish the potential for the UK in algae and to determine how this area could progress forward”<sup>23</sup>. While the input data to this study (collected in early 2011) is more extensive, the outcomes reported here are in general agreement with the observations made in the DECC report. In the intervening 1.5 years since the stakeholder meeting progress has been made in some areas; in many others the situation has deteriorated.

The research community still sees itself as fragmented and lacking impetus. Initiatives like BioMara, EnAlgae, the Carbon Trust ABC<sup>24</sup> and – more informally – the SPPI-Net working group on algae<sup>25</sup> have begun to draw together sub-groups across disciplines and universities as well as businesses, with promising initial results.

The NERC-TSB Algal Bioenergy Special Interest Group (AB-SIG) is intended to provide a “centralised point for strategy development, dissemination, information on funded projects and activity coordination”<sup>26</sup>. However funding for the Director (0.2 FTE) and the three research fellows (together 2.5 FTE) is only secured for two years. This initiative is an excellent start, and has the potential to make a significant impact. If the momentum is to be maintained, it is essential that follow-up funding (certainly for the strategic leadership aspects of the project) is secured, and preferably at increased levels; the challenge of high-level coordination of R&D across the UK cannot be met appropriately with a 0.2 FTE appointment.

Concerning funding for wider algal research, the situation has worsened since 2009. The withdrawal of funding from the Carbon Trust ABC<sup>27</sup> in April 2011 has been a blow not only to the 12 research teams involved, but also to the reputation of the UK internationally, since this project had been portrayed as the UK flagship for applied algal RD&D. As the 2009 DECC report stated, “A combination of lack of leadership, focus and clear policy objectives has resulted in the UK missing opportunities in algae development and it is clear the UK is now lagging behind other countries, most notably the USA”<sup>26</sup>. This gap has widened in the intervening time; it has to be recognised that it will grow to unsustainable levels unless steps are taken to mitigate the recent loss of funding and the lack of cohesion between algal researchers.

---

<sup>22</sup> The report is available at [www.nnfcc.co.uk/tools/assessing-the-potential-for-algae-in-the-uk](http://www.nnfcc.co.uk/tools/assessing-the-potential-for-algae-in-the-uk).

<sup>23</sup> *ibid* p. 7

<sup>24</sup> *c.f.* Section 1.2.3; the future of the Carbon Trust ABC is uncertain, since public funding was withdrawn in March 2011

<sup>25</sup> *c.f.* meeting report of SPPI-Net Algal Synthetic Biology Workshop on 24 March 2011, available at [www.sppi-net.org/downloads/AlgalSyntheticBiologyWorkshop0411.pdf](http://www.sppi-net.org/downloads/AlgalSyntheticBiologyWorkshop0411.pdf)

<sup>26</sup> 2009 DECC Report ‘Assessing the Potential for Algae in the UK’, p. 3; available at [www.nnfcc.co.uk/tools/assessing-the-potential-for-algae-in-the-uk](http://www.nnfcc.co.uk/tools/assessing-the-potential-for-algae-in-the-uk)

<sup>27</sup> [www.carbontrust.co.uk/emerging-technologies/current-focus-areas/algae-biofuels-challenge/pages/algae-biofuels-challenge.aspx](http://www.carbontrust.co.uk/emerging-technologies/current-focus-areas/algae-biofuels-challenge/pages/algae-biofuels-challenge.aspx)

## **Recommendations**

To develop the algal R&D field as a whole, it is recommended that BBSRC should work with the other Research Councils, the AB-SIG and stakeholders in academia and industry to assess which areas of algal research value chains the UK is best placed to develop, and thereby formulate a strategy for algal R&D in the UK. This strategy would best be realised by bringing the currently fragmented multidisciplinary algal research community together under the umbrella of a UK Virtual Centre of Excellence on Algae, with core funding being provided from across the Councils and Industry. Research would be funded *e.g.* through directed responsive mode grants and strategic longer and larger grants; a condition of such grants would be that the grantholder works with the Centre in the promotion of algal bioscience.

In order to pull algal R&D outputs through to commercialisation and consequently make their benefits tangible for the UK's emerging bio-economy, a joined-up approach across the Research Councils, TSB and all relevant Government Departments is needed. The Government has recognised the importance of mechanisms that facilitate the translation of the UK's world class research capabilities into economic benefit, and with the initiative to create Technology Innovation Centres has provided a funding mechanism to do so. The Research Councils may want to cooperate in engaging with the relevant Government Departments and TSB to create a national strategy on algae that spans research, development and deployment, and may recommend to the Government the establishment of an algal Technology Innovation Centre.

The combination of a strategically funded academic Centre of Excellence on Algae with a Technology Innovation Centre that takes step-changing research outputs through to commercial application would provide a complete and strong pipeline. Such a pipeline would guarantee high impact of UK algal research. It would provide direct benefit to the UK by both determining and realising the potential that algae have to contribute to a sustainable bio-based economy: it will in the short to medium term develop tangible solutions, and at the same time ensure that underpinning science is being put in place to address the long term challenges to mankind.