

# Blue Growth

## Scenarios and Drivers for Sustainable Growth from the Oceans, Seas and Coasts

Maritime Sub-Function Profile Report  
Marine Aquatic Products (2.3.)

Call for tenders No. MARE/2010/01

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*The research for this profile report was carried out in the period April – August 2011. This report has served as an input to the main study findings and these have been validated by an Expert meeting held on 9/10<sup>th</sup> November 2011 in Brussels. The current report serves as a background to the Final Report on Blue Growth.*



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# 1 State of Play

## 1.1 Summary description of the nature of the subfunction

The sub-function "Marine aquatic products" consists of the farming of marine aquatic organisms, mainly for human consumption and all the associated primary processing activities. While cultivation of aquatic plants and algae is still marginal in Europe, farming of aquatic animals is mainly composed of three major sub-sectors: marine shellfish farming (e.g. oysters and mussels), marine finfish farming (salmon, seabass and sea bream being the most important) and freshwater finfish farming (trout, carp, eel, etc.):

Within the context of this study, the Common Fisheries Policy will be seen as an important complementary policy development. However it seeks to identify complementarities with the CFP where appropriate and relevant, and aims to identify existing or new synergies with it. The EU is committed to promote the development of aquaculture. In 2009 the Commission adopted a Strategy for the sustainable development of aquaculture<sup>1</sup>. It focuses on 3 strategic objectives (competitiveness, sustainability and improved governance) and proposes a number of measures to be taken by the public authorities to address the challenges faced by the aquaculture sector. The Commission also proposes to promote sustainable development of EU aquaculture under the CFP reform.

*Given the attention already provided by the EC to farming of aquatic animals, it has been agreed to focus the research for this subfunction mainly on the potential of the cultivation of (micro and macro) algae and its products, an area which is still rather unexplored by the EC. The reporting on farming of aquatic animals will therefore be limited to a description of the "state of play " in this section.*

Some micro algae producers contacted in the framework of this study are not considered to be part of the aquaculture sector. Moreover, this subfunction covers production and extraction activities but not the transformation of raw material by biotechnological processes, which is covered by the subfunction "Blue biotechnology". Hence we focus here on "Algae aquaculture" – including both micro- and macro algae.

*Algae aquaculture* activities are currently at a very low scale in Europe although some algae products are widely used in the food industry (agar, carrageenan and alginates for example). Algae aquaculture activities consist in the cultivation of either macro algae or micro algae. They will be referred as "algae aquaculture". There are three distinct pathways to produce algae, which are at different development stages and face different constraints:

- Macro algae (seaweed) are mainly farmed at sea. European production is currently very low compared to Asian production.
- Autotrophic micro algae production takes place on land, in raceways or photo reactors, and is dependent on sunlight;
- Heterotrophic micro algae production is also taking place on land, in the dark of fermenters, replacing the support of light by a carbon source.

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<sup>1</sup> COM (2009)162 final. Communication from the Commission to the European Parliament and the Council: Building a sustainable future for aquaculture: A new impetus for the Strategy for the Sustainable Development of European Aquaculture.

Potential of micro algae as high-yield sources for lipids (20–50% dry weight) and fermentable biomass (starch and glycogen, 20–50% dry weight) has been documented in research conducted during the 1980s–1990s (Dismukes et al. 2008). Currently, start-up companies are working on the industrialisation of micro algae growing facilities for producing oils destined to human nutrition (omega-3 and omega-6 for example), animal feeding but also biofuel production (through for example HVO<sup>2</sup> process).

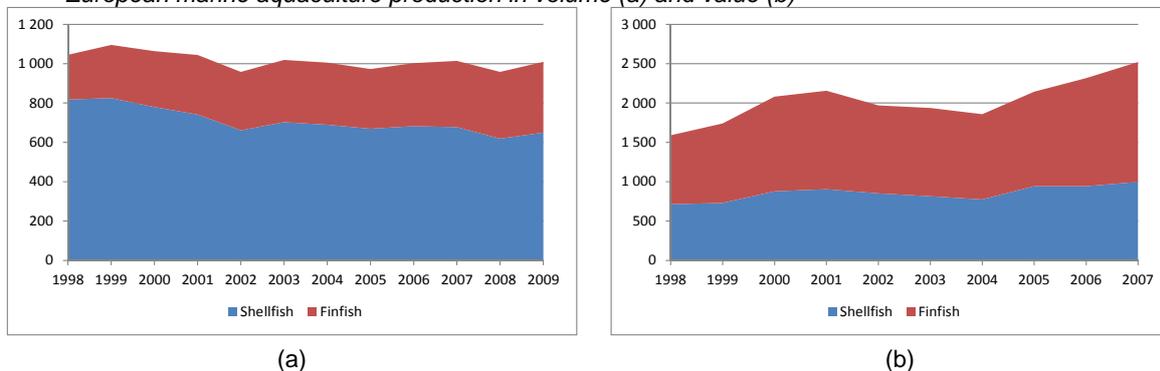
## 1.2 Description of the current structures

Before focusing on algae aquaculture, this section will provide basic information on the farming of aquatic animals.

### Farming of aquatic animals

Total aquaculture production in the EU is close to 1.3 million tonnes (Eurostat, 2009), worth some €3.3 billion (Eurostat, 2007). The overall production in marine and brackish water is slightly declining in volume but growing in value at the European level: Total production is estimated to reach €2.5 billion for 1.01 million tonnes in 2007<sup>3</sup> compared to €1.6 billion for 1.05 million tonnes in 1998. Over the period of 10 years, the evolution was not steady: the value produced has increased from 1998 to 2001 (then reaching €2.2 billion), decreased from 2002 to 2004 (€1.9 billion) and rebounded since then. In comparison, European freshwater aquaculture production decreased in value and volume from €820 million for 330,000 tonnes in 1998 to €750 million for 290,000 tonnes in 2007. Challenges for further development of EU aquaculture are numerous and include: limited access to space and water, red tape, industry fragmentation, pressure from imports, insufficiency of medicines and vaccines (COM (2009) 162).

European marine aquaculture production in volume (a) and value (b)



In 2006, the sector size was estimated to be around 16,400 firms while employment was believed to reach 63,700 FTE (for freshwater and marine aquaculture<sup>4</sup>, according to Framian, 2009). According to Ernst & Young et al. (2008), the EU aquaculture sector is composed mainly of SMEs and only a few players achieve more than €10 million in turnover (34 in 2006) across Europe<sup>5</sup>. Considering the different thresholds defining a SME<sup>6</sup>, Ernst & Young et al. (2008) identified only 8 companies falling outside the definition of SME.

<sup>2</sup> HVO for hydro treated vegetable oils, a technology turning vegetable oil into biofuel.

<sup>3</sup> It has been chosen to present data until 2007 only as Eurostat data for 2008 and 2009 are incomplete (no production value reported for large players: Greece, Germany...) or seem incoherent (production value reported for Spain and France).

<sup>4</sup> Neither Framian (2009) nor Ernst & Young et al. (2008) are reporting European wide data for marine aquaculture only. It has been chosen to avoid any assumption on respective shares.

<sup>5</sup> No data for shellfish aquaculture firms is reported in Ernst & Young et al. (2009), however the authors of this study highlight that shellfish aquaculture is composed for most part of very small enterprises.

<sup>6</sup> Commission Recommendation of 3 Apr. 1996 concerning the definition of small and medium-sized enterprises, 96/280/EC.

The aquatic food processing sector aggregates wild caught and farmed products processing. The latest GDP figures from 2007 are €4.3 billion for processing and employment levels of 116 000, although only a limited part of it relates to the processing of aquaculture products (Eurostat and Döring & Guillen 2009)<sup>7</sup>. Döring & Guillen (2009) do not publish any useful ratio concerning the sourcing between aquaculture and catching sector at the European level but give typical examples of national sectors with aquaculture supply routes (Belgium, Denmark, UK...). It has been chosen not to make any assumption about the relative share of aquaculture-sourced products in this sector.

According to Ernst & Young et al. (2008), 16 aquaculture firms achieved a turnover equal or higher than €20 millions in 2006:

- Pescanova<sup>8</sup>, situated in Spain, which aquaculture branch was believed to generate €270 million turnover in 2006 between its various turbot and shrimp farms in Spain, Portugal (Atlantic basin) but also its overseas production situated in South America;
- 8 were specialised in seabream and seabass production (7 in Greece, 1 in Spain – all in the Mediterranean basin);
- 4 were growing salmon, most of which are owned by Norwegian companies (all situated on the west coast of Scotland, and around Orkney and Shetland Islands – Atlantic basin and North Sea basin );
- 1 was growing turbot (in Spain – Atlantic basin);
- 1 was growing sturgeon in order to produce caviar (in Italy – Mediterranean basin);
- and 1 was dedicated to oyster production (in France – Atlantic basin).

As a comparison, Norway which is historically the world leader in salmon aquaculture has 39 firms achieving this turnover.

According to Ernst & Young et al. (2008), marine fish and shellfish aquaculture production activities are mainly situated:

- in the Mediterranean Basin (Greece, Italy, Spain and France) for the seabass and seabream productions,
- in the Southern part of the Atlantic Basin (France and Spain) for the mussel, oyster and turbot productions
- and in Scotland for the salmon production.

These particular locations concentrate the aquaculture activities because of a combination of excellent conditions, essentially water temperature and sheltered coasts to grow these particular species (except for turbot which is grown on land):

- Mediterranean waters are amongst the best waters to grow seabream and seabass, as the Northern European waters for salmon.
- The European coasts have natural populations of mussels which have been harvested as spat then grown in coastal areas for decades. Mussel culture is historically well developed in the southern part of the Atlantic basin (Spain, France), in the North Sea basin (Belgium, the Netherlands and Denmark) and in the Mediterranean basin (Italy).
- Oyster production mainly occurs in the Atlantic basin where growth rates are economically interesting (France, Spain, UK and Ireland), some of which are also spat collecting areas.

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<sup>7</sup> For the processing sector, the data used are sourced from Eurostat as they seem more consistent than the one published by Döring & Guillen (2009).

<sup>8</sup> Pescanova is a Spanish conglomerate involved at various stages of the fishing industry: catching, fish processing, aquaculture.

## Algae aquaculture

Algae aquaculture activities are less developed at the European level than fish and shellfish activities.

Macro algae (seaweed) are macroscopic multicellular organisms growing from photosynthesis, harvesting sunlight energy and fixating CO<sub>2</sub>. They can be farmed (aquaculture) or exploited by extraction from natural populations in coastal areas (algae extraction). The European macro algae aquaculture production oscillates between 30 and 60 tonnes per year between 1998 and 2008 according to FAO data<sup>9</sup>. In comparison, the European algae extraction sector produced 73,000 tonnes in 2007, in decline from a production of 123,000 tonnes in 1998.

According to interviews, macro algae are mainly farmed at sea in Europe. It was also stated that the European macro algae aquaculture sector is almost non-existing when compared to major Asian producers (China, Japan).

It has not been possible to identify data for micro algae in official dataset (Eurostat), nor useful publications describing it. Estimation of global production vary between 5,000 (Wijffels & Barbosa 2010) and 10,000 tonnes (interviews), which is overall very limited compared to other farmed commodities<sup>10</sup>. According to interviewees, the global demand for micro algae biomass does not currently exceed the offer.

According to interviews, most algae producers are currently in development stage, and are focusing both on freshwater and marine micro algae, depending on the final product they are aiming for. Contrarily to finfish and shellfish aquaculture, there is no clear distinction between freshwater and saltwater (saline and brackish waters) production of micro algae. Most micro algae can grow in a wide range of salinity and adjustment in salinity may lead to different final products (Chen & Chen 2006).

Due to their small size, micro algae cannot be cultivated in open waters as they cannot be easily contained: micro algae are produced on land either in open ponds or in closed system called bioreactor. Microalgae are unicellular organisms also growing from photosynthesis which is called the "autotrophic pathway". Some micro algae can also grow in the dark supported by a carbon source (glucose, glycerine...) replacing the traditional support of light energy, which is called the "heterotrophic pathway" (Perez-Garcia et al. 2011). In both pathways, micro algae need nutrients to grow, such as nitrogen, phosphorus, sometimes silicon (for diatoms algae), but also micro-nutrients (iron...). Autotrophic productions need also an additional CO<sub>2</sub> supply to allow high yield.

Most European producers are growing micro algae following the autotrophic pathway either in open ponds or in closed photo bioreactors (bioreactors designed to enable maximum light availability to the algae culture).

- Open ponds and raceways production is highly demanding in space. Production conditions can be partly optimised (nutrients, CO<sub>2</sub> adjunction) although it is difficult to control all of them (temperature, light, and contamination by birds or bacteria, pollution). The simplicity and low costs of this technique make it attractive to producers facing low land pressure and high solar radiation: in this respect, countries such as Australia and USA have a geographical advantage compared to Europe.
- Closed photo bioreactor production needs less space and allows a more controlled culture environment (temperature, salinity, nutrient concentration, CO<sub>2</sub> concentration...) which enables

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<sup>9</sup> Data for value reported by FAO seem inconsistent and it has been decided not to report them in this document.

<sup>10</sup> As a comparison, producing 10,000 tonnes of corn grain would only necessitate 1,100 hectares in France according to Arvalis, a French technical institute (average yield for French corn producers in 2010: 9.15 tonnes per hectare).

less contamination, more constant quality, higher density of algae biomass in culture medium and often higher yield. This type of production has higher energy needs to maintain a constant flow in the photo bioreactor. It is also more capital intensive due to the bioreactor construction and maintenance costs.

According to interviews, a limited number of European businesses follow the option of heterotrophic production. This type of production can be undertaken in classical fermenters used in the biotechnology sector, where all conditions can be controlled and optimised (Green & Green 2006). In the USA, major players like Solazyme<sup>11</sup>, Honeywell's UOP, Amyris, Sapphire Energy, Heliae and Martek are the most well known R&D companies working on micro algae production, of which Solazyme and Martek focus on heterotrophic production.

Due to the containment design, saltwater ponds, photo bioreactors and fermenters can be installed almost anywhere on land. Saltwater used for the production can be either pumped from the sea (seawater) or produced by salt adjunction to freshwater (produced saltwater). A recent American study evaluated that "produced water [i.e. adding salt to freshwater] may be a viable source for high bio fuel production areas in Southern California, the Gulf Coast, and the South-Central United States" (Wigmosta M. 2011). From a water resource management perspective, this technique may be questionable, especially in river basins where freshwater is scarce and where tensions already exist on water usage.

Specific demand of several markets can be met by both macro algae and micro algae aquaculture:

- Algae extracts are used in *cosmetic, nutraceutical and pharmaceutical markets* (macro algae and micro algae). There are already several products on the market such as PUFA's (poly unsaturated fatty acids) like omega-3 and omega-6, but also antioxidants.
- Macro algae producers can target the human *food market* (already happening in Asia) but also the animal feed market. Some interviewees believe that macro algae will be a valuable source of proteins for human and animal consumption. Micro algae producers may also reach these markets once the production levels have increased.
- The *energy market* will be mainly interested in the oil contained in micro algae and in the capability for macro algae aquaculture to produce large amount of biomass.
- Finally, algae can potentially be used for other *yet unexploited purposes*, including chemical processes, such as the use of brown algae in high-capacity Li-Ion batteries (I. Kovalenko et al, 2011). But also carbon storage and reduction in water pollution can be mentioned here.

### 1.3 Regulatory environment

In the European Union the development and the management of aquaculture is of Member States' competence (e.g. regarding access to water and space, allocation or renewal of licenses, etc.). However, for many aspects which concern aquaculture (food safety, animal health, environmental issues, etc.) the EU has established an important legislative framework in order to coordinate and harmonize national laws.

Key EU legislation<sup>12</sup> affecting directly the algae aquaculture sector is:

- The Water Framework Directive<sup>13</sup> applies to inland waters and coastal water up to 1 nautical mile. At the Directive's core is a set of environmental objectives, which include achieving good

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<sup>11</sup> Solazyme has been awarded several contracts with the U.S. Department of Defense for provision of algae derived fuel for various army vehicles (ships, jets, helicopters...)

<sup>12</sup> In the framework of Blue Growth, it has been decided to concentrate only on EU wide regulations.

<sup>13</sup> European Parliament and Council Directive 2000/60/EC establishing a framework for Community action in the field of water policy.

ecological and chemical status of surface water within 15 years of the Directive entering into force. There is some concern in the aquaculture industry about the potential for the WFD to constrain the development of aquaculture, however not for the algae side of the sector (Hedley & Huntington 2009). The Marine Strategy Framework Directive<sup>14</sup> is in essence the continuation of the Water Framework Directive beyond the 1 nautical mile limit. Hedley & Huntington (2009) note that the concentration of aquaculture activities is currently lower outside the first nautical mile but that the development of aquaculture at a larger distance from the coastline might increase the relevance of the MSFD.

- In May 1992 European Union governments adopted legislation designed to protect the most seriously threatened habitats and species across Europe. This legislation is called the Habitats Directive<sup>15</sup> and complements the Birds Directive<sup>16</sup> adopted in 1979. At the heart of both these Directives is the creation of a network of sites called Natura 2000. Natura 2000 sites are protected areas where aquaculture activities are limited or prohibited.
- The Council Regulation concerning use of alien and locally absent species<sup>17</sup> in aquaculture aims at controlling the spread of aquaculture species in Europe to ensure adequate protection of the aquatic environment from the risks associated with the use of non-native species in aquaculture.
- Until recently, animal feed legislation was based on two regulations<sup>18</sup> imposing a pre-market authorisation for any ingredient used for the preparation of feeding products. Algae producers very seldom requested such authorisation due to the high costs associated to the authorisation process, limiting therefore the markets algae producers could target (Garofalo 2010). The new regulation on the placing on the market and the use of feed<sup>19</sup> does not impose the pre authorisation any more. It is not clear from the different interviews if this new regulation has effectively allowed micro algae producers to enter the animal feed market.

## 1.4 Strengths and weaknesses for the subfunction

The European algae aquaculture strengths (S) and weaknesses (W) are to be separated from macro and micro algae:

### Macro algae

- Production sites:
  - (S) There are large sea surfaces suitable for the development of macro algae aquaculture for which there are currently few competitors.
  - (S) Macro algae aquaculture can be developed in conjunction with other usage (wind farms, tidal farms...) and have beneficial functions such as wave reduction (erosion reduction).
  - (W) The availability of new sites for macro algae aquaculture close to the coastline is now heavily restricted on grounds of protecting the environment or visual seascape, or through competition with more economically attractive tourist development.
  - (W) Risks of offshore floating structures are not well studied. The large distance from land will lead to costly installation, production and harvest.

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<sup>14</sup> Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for Community action in the field of marine environmental policy

<sup>15</sup> Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora

<sup>16</sup> Council Directive 79/409/EEC of 2 April 1979 on the conservation of wild birds

<sup>17</sup> Council Regulation (EC) No 708/2007 of 11 June 2007 concerning use of alien and locally absent species in aquaculture.

<sup>18</sup> The Council Directive of 30 June 1982 concerning certain products used in animal nutrition (82/471/EEC) and the Council Directive 96/25/EC of 29 April 1996 on the circulation of feed materials [...]

<sup>19</sup> Regulation (EC) No 767/2009 of the European Parliament and of the Council of 13 July 2009 on the placing on the market and use of feed [...]

- Technologies:
  - (S) Large scale production of macro algae viability has not to be demonstrated as it is already happening in Asia for decades, due to a well-developed Asian food market for seaweed.
- Market:
  - (S) There is already a market for high value extracts from harvested macro algae (cosmetics, nutrition...) which could be targeted by the macro algae aquaculture sector.
  - (S) Macro-algae are expected to help fulfil a growing demand in proteins for human and animal consumption
  - (S) The strong demand for biomass for energy is expected to benefit to the development of macro algae aquaculture.

### Micro algae

- Production sites:
  - (S) Photo bioreactors and fermenters can be installed almost anywhere and associated production sites do not need large surfaces to be viable. Light intensive regions will have an advantage to attract businesses developing photo bioreactors.
  - (W) On-land development face higher competition for surface than other continents (especially USA and Australia), especially for open systems (ponds, raceways).
- Technologies:
  - (S) Quality of micro algae products is generally easy to control in systems (both autotrophic and heterotrophic), by controlling strain selection (lipid content, protein content), growing conditions, harvesting conditions. Heterotrophic micro algae can grow in the dark, which requires less special light criteria, and could require less energy overall.
  - (S) Production of PUFA's (poly unsaturated fatty acids) as well as anti oxidants by micro algae seems most promising in the short term as current production costs are compatible with market demand. Depending on production conditions and strain selection, micro algae can contain either a large proportion of proteins or lipids.
  - (S) Some major technological developments have been supported by the biotechnological sector, allowing micro algae producers to access to well establish technologies (bioreactor design, control systems, concentration and drying).
  - (W) The relative limited size of the sector might lower the potential for ad-hoc R&D. There are still key technological gaps to be filled before industrial scale to be reached. Also, there is not a lot of knowledge exchange / technology transfer between actors on this market; there are many different decentralized initiatives for various niche markets.
- Market:
  - (S) The strong demand for specific products (omega-3 fatty acids...) which can already been viably produced may trigger the development of new micro algae producers.
  - (W) According to interviewees, the global production of micro algae biomass is estimated to reach 10 000 tonnes, which is very limited compared to other farmed commodities<sup>20</sup>. These 10 000 tonnes were just absorbed by the global demand.

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<sup>20</sup> As a comparison, according to Arvalis, producing 10 000 tonnes of corn grain would only necessitate 1100 hectares in France in 2010 (average yield for French corn producers in 2010: 9.15 tonnes per hectare).



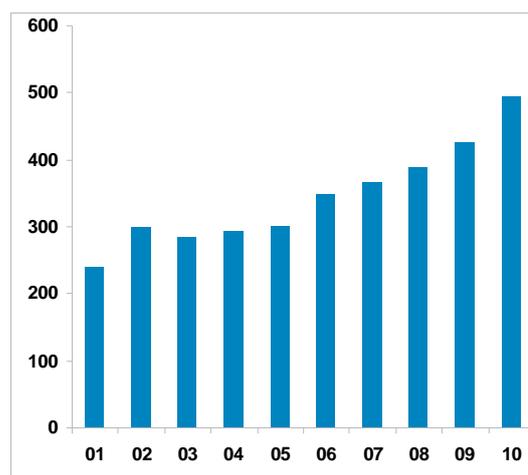
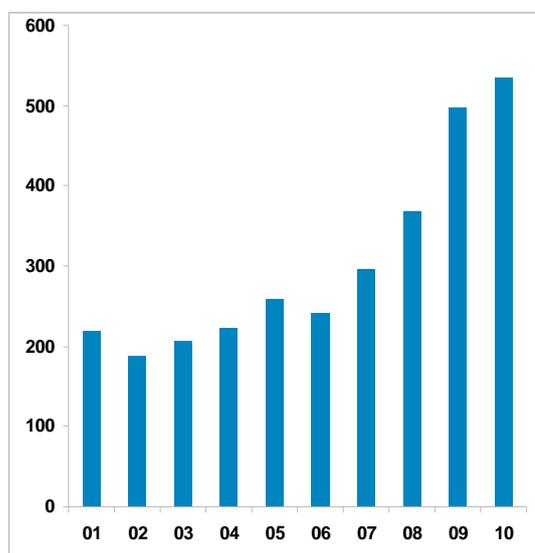
## 2 Research and technology

### 2.1 Research & Technology mining patterns

Total number of global inventions and publications related Algae Aquaculture (2001 – 2010)

Invention

Publications



Source: Thomson Reuters

The rising number of global inventions in the past two years and more so of the publications in the course of the last decade gives a clear outlook of the increasing importance of Research and Technology in this function.

The table below compares EU-27 countries in terms of patents filed on their grounds, with competing countries (2001–2010). Priority country means the place where the invention was invented and filed.<sup>21</sup>

Table 3: Country score in inventions related to Algae Aquaculture

Priority countries	Total inventions (2001 - 2011)	% of global
Japan	1416	25%
US	1022	18%
EU-27	878	16%
China	756	13%
South Korea	261	5%
Global	5627	

Source: Thomson Reuters

Figures above indicate that Japan is leading in terms of inventions, with 25 % of global inventions tightly followed by the US with 18%. The EU-27 countries together follow tightly with 16%.

<sup>21</sup> Priority country is used in the absence of an inventor county within the patent data. The particular field is not present across a good amount of authorities

Table 4: Country score in scientific citations related to Algae Aquaculture

Priority countries	Total citations (2001 - 2011)	% of global
EU-27	12769	42%
US	4620	15%
Japan	1322	4%
China	866	3%
South Korea	417	1%
Global	30577	

Source: Thomson Reuters

Table 5: Country score in published papers related to Algae Aquaculture

Priority countries	Total published papers (2001 - 2011)	% of global
EU-27	1854	37%
US	779	16%
China	349	7%
Japan	265	5%
South Korea	84	2%
Global	5010	

Source: Thomson Reuters

Similar to observations for other subfunctions, in terms of research and technology mining patterns, the EU-27 is ahead of the field of scientific and of published papers.

Table 6: Top 20 global patent assignees - organizations or individual owners of the patent's invention - are presented in the table below in Algae Aquaculture

Top assignees	Total number of patents filed (2001- 2011)
Bayer Group	64
Mitsubishi Group of Companies	57
CHUGOKU TORYO KK	54
Chinese Academy of Sciences	51
Nippon	47
Sumitomo group	42
SHINETSU CHEM IND CO LTD	25
UNIV CHINA	24
DAINIPPON TORYO KK	23
NIPPON SODA CO	23
XINAO SCI&TECHNOLOGY DEV CO LTD	23
NIPPON OILS & FATS CO LTD	20
PENTEL KK	19
CHUGOKU MARINE PAINTS LTD	18
KAIYO BIOTECHNOLOGY KENKYUSHO KK	18
UNIV DALIAN	18
KANSAI PAINT CO LTD	17
BASF	16
BUCKMAN LAB INT INC	16
HITACHI	16

Source: Thomson Reuters

With a great number of companies (assignees) based in China or Japan, Desalination can be considered a market where EU companies are currently under-represented in comparison to the relative scientific output – publications and scientific citations - of EU research institutes.

## 2.2 Assessment of patterns observed

Over the last ten years, the annual number of scientific publications dealing with macro algae and micro algae has constantly increased. Patent publications have been almost following the same rising trend. Europe is generating by far the most important part of scientific *publications* (40%) with a group of leading European countries: Germany, the United Kingdom, Spain and France. In the meantime, the USA was publishing 16% of the scientific papers, followed by China (7%), Japan (5%) and Australia (5%).

When comparing this scientific activity to the trend in *patents* publication, difference are striking: Europe only represents 16% of patents filled in relation to algae and micro algae usages.

Europe is surpassed by Japan (25%) and the USA (18%) and closely followed by China (13%).

Top authors in this field are seldom listed as top patent assignees, whether considering institutions or individual researchers. These differences in publication patterns can be explained by possible differences in procedure to fill and grant patents between countries. There seems to be however a fierce competition between large chemical groups which do not publish scientific papers but file an important number of patents: Bayer in Europe, but also several important Asian groups (Mitsubishi, Chugoku Toryo, Sumitomo, Shinetsu Chem). Major Chinese universities and public institutes are also following the trend toward more patents.

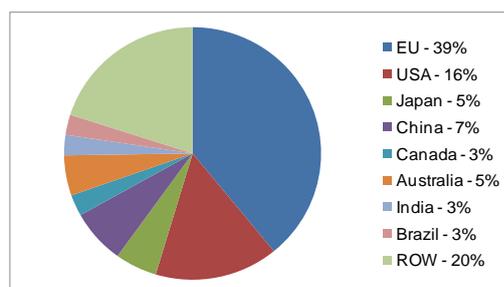


Figure 1: Scientific publication

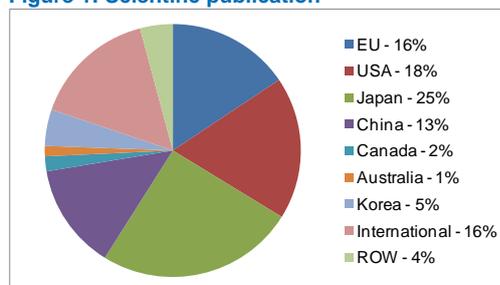


Figure 1: Patent publications

The R & D developed in the European algae aquaculture benefits from EU funding, covering several key aspects for its development:

**Macro:** Outside of experimental activities in the Netherlands, Ireland, France and Germany, there is not a lot of activity in Europe in the field of macro algae culture systems. These researches mainly concentrate on the improvement of cultivation techniques, and on the

### Case: Seaweed culture pilot installation in the Eastern Scheldt estuary, the Netherlands.

**Why this Case is important:** This 'Seaweed-farm' pilot by Wageningen Plant Research International can showcase the future commercial potential of seaweed culture, is essential for valuable knowledge development in terms of production ecology as well as environmental effects (negative and positive) on ecology, morphology and coastal safety, and contributes to societal acceptance of the shift from agriculture to mariculture.

**Key description of the case:** The seaweed culture installation pilot focuses at various aspects of seaweed culture: **technical** aspects (how strong is the installation, how will it resist and attenuate waves), **biological** aspects (which species grow best under which circumstances), **environmental** aspects (what negative or positive effects does an installation have on its environment), **market** aspects (what kind of commercially valuable substances can be produced, how much and at which costs) and **societal** aspects (how will the pilot affect other users of the area).

**Future developments:** Knowledge on the environmental benefits of seaweed culture in terms of strengthening the environment and enhancing coastal safety will support further innovation towards **Integrated Multi-Tropic Aquaculture**.

biological and economic viability of cultivating macro algae:

- Selecting the best strains to be cultivated,
- Optimising the hatchery culture conditions,
- And defining the culture practices to achieve constant high yields (including nutrient enrichment).

**Micro:** Micro algae aquaculture research seems to be mainly focused on three main aspects at the European level:

- Improving the strains of cultivated algae, like in the project GIAVAP (Genetic Improvement of Algae for Value Added Products);
- Achieving the industrialisation of processes currently available at the pilot scale (production, drying, extraction...);
- Evaluating the potential of micro algae to produce biofuel, several demonstrator projects are supposed to start early 2011 following the last FP7 Energy Call<sup>22</sup>.

Internationally, the main competitors in terms of research are:

- China where strain developments of macro algae are currently taking place. Large scale production of macro algae already occurs in China.
- Australia, through its network BEAM (for Biotechnological and Environmental Applications of Micro algae) which has a specific research group dedicated to the development of algae biofuel. The Australian government launched in 2009 a multi-million research project to explore biofuel developments, in which micro algae is considered as a potential feedstock. There are also developments of on-land production of macro algae.
- USA: the US Department of Energy has developed a national algae biofuel technology roadmap (US Department of Energy 2010) aiming at fostering R&D to achieve industrial applications of micro algae production (Solazyme algae biofuel demonstrator for the US Navy for example). Although this support can be seen as military-driven, it has to be noted that the US government has a long-standing habit to support highly innovative research through military funding, which has no equivalent in Europe.
- Israel has a particular interest toward open raceways technologies for the production of micro algae. Public research institutes and private firms are often part of EU-funded research consortiums (under several FP6 and FP7 calls).

There are key technical developments to be achieved in the algae aquaculture sector before the sector can grow:

### **Macro algae aquaculture**

There are very good examples of large scale production of macro algae in Asia, which benefits from a long standing tradition of algae cultivation but also from low labour costs (especially China). Adapting this production to European waters necessitates 1- to select and improve through breeding local strains of macro algae suitable for cultivation and 2- to define low cost, high efficiency and sustainable (low impact) modern cultivation system with minimal use of labour to be able to compete with Asian producers.

According to interviewees, the largest obstacle for upscaling macro algae production is that large-scale production is hard to control in order to enable a constant high yield of productivity. The available knowledge has been mainly obtained in the field of marine biology, based on natural ecosystems observations. Major knowledge development is required in the field of production-

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<sup>22</sup> FP7 ENERGY.2010.3.4-1

ecology in order to optimise the production conditions, which are different than for naturally grown seaweed. Nutrients needs of algae farms is an important issue as it could be a limited factor in some areas. It is expected that macro algae will mostly develop in cold waters: according to interviewees, the Mediterranean and Black Seas are not well suited to host algae cultivations. This is due to lower nutrient content of these waters (lack of upwelling from deeper oceans), but also due to temperature related higher competition from naturally occurring micro algae species and other organisms (more algal blooms in summer lead to massive uptake of nutrients).

The development of integrated multi-tropic aquaculture operations mixing several productions on one site has still to emerge at the European level, although research is already taking place in the Netherlands. Also, there are various research programs starting in 2012 as part of the FP7 Oceans call for Multi-use Offshore Platforms. Traditionally occurring in South East Asia, some trials of multi-tropic aquaculture are pursued in Canada (New Brunswick).

Processing techniques of macro algae does not seem to be the biggest challenge for interviewees: current yield of biomass conversion are reasonable and can still largely be improved.

### **Micro algae aquaculture**

According to interviewees, the major technologies for micro algae production are already available as they are mostly spin-off of the chemistry and biotechnology sectors. Interviewees' opinion is that the real technological issues lie in the process development: how to scale-up what is currently achieved at the pilot scale, while maintaining viable economic conditions for businesses to operate. According to interviewees, the key steps still to be achieved to unleash the micro algae potential concern:

- The design of photo bioreactor allowing productions exceeding an annual volume of one tonne of biomass. Scaling up the design of photo bioreactor leads to several technological conundrum:
  - the light dispersion inside the PBR is decreasing with the size, lowering the productivity level of the algae,
  - The micro-fouling occurring inside the PBR is also lowering the light dispersion. Specific solutions to combat this particular type of fouling are still to be found,
  - For extensive upscaling, nutrient availability will most likely be the limiting factor. Focus should therefore be put on cultivation and processing methods that enable nutrient recycling.
  - the CO<sub>2</sub> level which have to be delivered to the algae as the CO<sub>2</sub> levels in the air are not sufficient for high productivity and additional CO<sub>2</sub> supply may be necessary to increase yields, which poses a great opportunity for combining production sites with large CO<sub>2</sub> emitters.
  - The head loss is increasing with the size of the PBR, which will necessitate more energy to be devoted to the pumping system. It is currently one of the major bottlenecks to be overcome to reduce PBR operating costs.
- the extraction phase of the fraction of interest (lipids or other products), and means of extraction:
  - Generally, micro algae have to be concentrated and/or dried to some extent before the molecule of interest (lipid, protein or biomass) can be exploited. Currently, four technologies are looked at to concentrate the algae (flotation, sedimentation, filtration, centrifugation), none of which is achieving adequate yields at acceptable costs (essentially energy costs) for large scale productions
  - Extracting interesting molecules without damaging micro algae ("milking") is one of the techniques which would allow continuous production, increasing production yield. Research is being conducted on wet extraction methods, which enables extraction with limited drying efforts. This reduces energy consumption, but would simultaneously facilitate nutrient

recycling. This is regarded as a very promising and crucial field of R&D to make large scale extraction feasible and cost-effective.

- the improvement of algae strains through screening and domestication of new algae strain,
- The optimisation of culture conditions (temperature, light, algae concentration, input adjustment, managing bio fouling, O<sub>2</sub> accumulation) to achieve better yield. As mentioned before, researches have demonstrated that for a same micro algae strain, adjustment in salinity may lead to different final products (Chen & Chen 2006). Other variations in nutrient concentration can lead same algae to synthesise different final products.

It has been mentioned by some interviewees that autotrophic micro algae culture are highly dependent on solar radiation, implying that yields are negatively correlated to distance to the equator. According to interviewees, this constitutes a limit to the potential R&D progresses: the northern part of Europe is expected to be handicapped compared to Mediterranean countries. Interviewees also indicate that rigorous frost may also be a potential obstacle for profitable micro algae developments.

Overall, achieving robust and stable cultures at a commercial scale is the major challenge: interviewees stressed the fact that overcoming all these technological gaps does not mean that a continuous highly productive production can be achieved.

Besides technical achievements, evaluating the environmental benefits of algae production in terms of carbon fixation (opportunities for carbon offsetting) and nutrient filtration capacities (opportunities for waste water treatment) is also a research priority which should not be overlooked according to interviewees. There is also a need for the proper identification of environmental risks and impacts of cultivation systems leaches (and associated mitigation measures) as micro algae cultivation systems are rich in biomass and concentrated in nutrients (Nitrogen, Phosphorus, Potassium).

## 3 Future developments

### 3.1 External drivers affecting the performance of the cluster

The algae aquaculture sector is a relatively new sector in Europe. According to some interviewees, the sector suffers from a lack of entrepreneurial culture in Europe as few investors are keen to take risks in these new technologies, especially in the production of micro algae.

Access to finance is a key issue for this sector, as interviewees mentioned that banks seem reluctant to finance farms development, as aquaculture is regarded as a high-risk sector to invest in. Access to venture capital seems also to be difficult for new aquaculture developments. Investors and insurers might see even more risks in offshore aquaculture (large initial investments, costly maintenance...), and especially if aquaculture operations are developed in international seas (outside the 12 miles).

Biofuel from algae is currently a high profile topic in Europe but also in the USA, which may allow businesses to access to capital more easily. Most interviewees believe that it may be detrimental to the sector if the biofuel applications do not prove to be economically viable in a short to medium turn, as it would send a negative signal to potential investors.

There is a growing demand for products which can be produced through algae pathways such as omega-3 or omega-6 fatty acids. It is already economically profitable to produce some of these substances with current technologies, allowing existing and new businesses to capitalise on these markets before expanding. The European sector has also to compete with more established companies (USA, South East Asia, Australia), which seem to be more advanced both in macro algae and micro algae aquaculture productions. It has been mentioned by interviewees that European micro algae producers had difficulties to sell their products on the European animal feed market (see section 1.3 page 11) while their main Japanese and North American competitors were the prime provider for micro algae biomass used in European aquaculture (although we were not able to confirm this with trade data).

The expected phosphorus limitation in agriculture in the following decades is an important driver to develop culture systems in which phosphorus can be fixed from the natural system. Macro algae culture in open seas enables the fixation of phosphorus that has run off from agricultural lands.

Interviewees believe that rising conflicts for land use between food and oil crop will help the macro algae sector to overcome the incrimination of visual pollution they encounter in coastal areas. For them, raising awareness is one of the keys to sector development: if the general public recognises the various benefits of macro algae cultivation, macro algae farms will be better accepted and able to flourish. The benefits that interviewees foresee are mainly that macro algae do not need fresh water, do not occupy land, can store carbon and can help in reducing water pollution (especially nutrient leaches).

### 3.2 Assessment of response capacity and commercialisation potential

The micro algae aquaculture sector is highly focused on integrating the latest R&D developments. There is however a lack of knowledge-sharing between companies which are very closed and secretive, and do not share information easily. This leads to an overall slow learning process, which is hampering knowledge development in this sector significantly.

The micro algae sector is already supplying niche markets (omega-3 fatty acids, cosmetic products for example). Access to larger market still needs key developments to be achieved to allow production scale-up. However some interviewees commented that yeast and fungi benefit from high yields and are able to produce almost every compound through transgenesis. Micro algae developments will have to prove their competitive advantage to attract investors, and need to aim to serve multiple purposes and markets, and enable better cascade processing.

On the other hand, macro algae producers do not need to prove that large-scale production is feasible as it already happens in Asia. They however have to demonstrate that it can be adapted to European conditions (local strains of algae, high labour costs) in profitable and sustainable conditions. It has for example to prove viable without large fertilization as it can happen in some farms in Asia. One of the major challenges for the sector is to raise awareness among policy makers and industrial customers.

Overall the response capacity of the European actors is considered relatively low due to:

- the limited size of sector, decentralized initiatives, limited exchange and slow learning process;
- the highly specialized production processes;
- the limited markets, which are currently niche markets;
- The high investment costs needed to start novel production facilities for macro algae or micro algae.

### 3.3 Most likely future developments (the Micro-future)

**Micro algae** will be used as precursors of multiple products (concept of biorefinery) from cosmetic additives, to feed and food, to energy feedstock. Interviewees agree in considering that the algae sector has significant chances to grow over the next 20 years, in a three stage progression:

- The sector is emerging as a niche market focused on high-priced products for the health and cosmetic sector<sup>23</sup> (between 2010 and 2015).
- It will then grow as a medium-sized market producing metabolites and primary compounds (proteins, lipids, sugars...) to be incorporated by the food and feed processing industry (for human consumption and animal feeding) (around 2020).
- In a third stage, the algae sector will become a provider for mass product markets, with two major clients: green chemistry (polymer precursors...) and energy (2025-2030). In this vision, groundbreaking photo bioreactors designs and extraction processes allow the micro algae production scale up within viable economic conditions.

**Macro algae** farms are developed along the coast, sharing space with other sectors on multi-purpose platforms combining several activities such as integrated multi-tropic aquaculture<sup>24</sup> (also called IMTA), and other activities (wind, coastal protection...).

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<sup>23</sup> To avoid overlap, the subfunction "High value use of marine resources" is focusing on the different activities aimed at developing new usages of marine resources and is limited to R&D for the purposes of this study.

<sup>24</sup> Multi-tropic aquaculture is based on interlinked productions of fish, seaweed and shellfish.

A radical future path emerges as some interviewees do not believe that micro algae production will ever be competitive enough to allow its products to fulfil the biofuel and chemistry sectors. In their vision, several bottlenecks will not be completely overcome, hindering the micro algae sector to lower its costs at a sufficient level to the mass-products markets. The main blockage resides in the extraction phase which would remain too energy-demanding to allow reasonable costs to be achieved. Other blockages concern the photo bioreactor design and the overall energy balance of the production which might be negative: more energy being used in pumps and extraction processes than produced by photosynthesis.

The key elements which differ from the two visions are: 1) the ability of the micro algae sector to lower its costs at a competitive level to enter these mass product markets and 2) the competition of other feedstock as biofuel precursors like jatropha<sup>25</sup>, salicornia<sup>26</sup> or other oil-rich plants.

Interviewees indicate that the evolution speed of the algae sector mainly depends on few key drivers which are:

- the access to finance and mainly the ability of the European sector to attract private investors to enter the sector on the medium to long term – interviewees indicated that investors seem currently more reluctant to invest in European businesses compared to US companies, which is probably related to the R&D stimulating policies by the US government;
- the capacity of the European sector to be competitive on the global market compared to major players (USA, South East Asia, Australia);
- the ability of macro algae farms to access large sea areas, which depends on the willingness of national governments' marine spatial planning departments, but also on the acceptance of coastal communities;
- the response to potential stimulations by National/European research funds although some interviewees indicated that such stimulus may not be necessary for the micro algae sector to develop;
- The capacity to avoid a second boom and bust cycle: some interviewees mentioned that micro algae developments were high on the agenda during the 80s before an almost complete blackout during the 90s<sup>27</sup>. The recent regain in interest is seen as a potential risk: if current biofuel demonstrator projects are not achieving

**Case: Advances in micro algae bioprocesses**

*Why this Case is important:* The current push for biofuel demonstrators is sometimes seen as a step too far considering technologies currently available: in case of failure, a negative signal will be sent to investors, diverting capital from a promising sector.

*Key description of the case:* Micro algae development is currently at a crossroads as several research centres and SMEs have achieved pilot-scale productions, when political attention is focused on micro algae-biofuel in Europe but also in other countries (USA, Australia).

Some interviewees believe that these biofuel demonstrators will not foster but slow down innovation: to be successful and achieve the requested yields, these three year projects can only be based on technologies already existing prior to the projects, while the sector is still in need for more ground breaking developments.

*Future developments:* Developments to be performed are mainly concentrated on two aspects: 1- designing large photo bioreactors: photo bioreactors need more research as up scaling lead to several conundrums and 2- extracting the final product. This process is currently highly energy-demanding which makes economical sense only for high value products.

*Impacts on blue growth:* Allowing the resolution of several technical bottlenecks will foster technological competencies at the European level but also maintain the European sector in the 3rd generation biofuel race. These research results may also have significant importance for other sectors (biochemistry...).

<sup>25</sup> Jatropha is a tropical shrub which may be exploited for its oil-rich seeds as a precursor for biofuel.

<sup>26</sup> Salicornia is a salt tolerant plant which may also be exploited for both its straw and its oil-rich seeds as a precursor for biofuel (Stratton et al. 2010). NASA and the US Department of Energy are currently studying its large-scale cultivation in semi-desert area.

their objectives, the negative signal sent to investors might divert funding from the entire sector, and not merely the algae fuel part.

- It also will depend from large energy companies' willingness to invest in developing alternative resources. Most large oil companies have invested in micro algae pilot productions developed by innovative SMEs, although some key players are currently sending contradictory signals by lowering their support to this sector<sup>28</sup>;
- Policies that stimulate renewable energy production and consumption, increasing costs of GHG emission rights, and increasing prices of traditional fuels will have a stimulating effect on the biofuel market as a whole. With increasing land-use pressures, algae-fuel will have a beneficial position over other biofuel crops, as it requires less (micro algae) or no space (macro algae) on land. The high production and processing costs will remain an obstacle if demand is low.

### 3.4 Impacts, synergies and tensions

#### Micro algae

Most interviewees believe that the growth of the sector will not lead to the creation of numerous micro algae producers at the European level, but rather into a concentrated sector of a few large producers. Estimations of the number of large producers vary between 10 and 30 rather than 100 and 300). Some interviewees believe that small photo bioreactors could be integrated almost anywhere (roofs, walls...) allowing a more decentralised sector to grow.

In terms of job creation, the limited size of the micro algae sector will not allow the sector to be a large employer at the European level. If the sector remains concentrated, as expected by interviewees, the development of micro algae production in Europe could generate the creation of 1000 to 2000 direct jobs. Further down the supply chain, interviewees expect more a substitution effect which would overall not create jobs, as algae ingredients will replace other ingredients in end-products.

Considering potential environmental impacts, it has been mentioned that micro algae aquaculture is a CO<sub>2</sub> sink, as algae species require CO<sub>2</sub> for growth (except for the heterotrophic pathway). Taking all production steps into account, micro algae aquaculture could have a neutral to positive impact on CO<sub>2</sub> levels in a region.

As micro algae aquaculture takes place in closed systems, the nutrient rich effluents are not released into the surrounding environment. The culture installation might even use waste-water effluents as a source of nutrients for the algae (only if the end product is not destined for the food or feed market). As such, the installation could have a positive impact on overall water quality. Energy requirements in the processing phase are high; depending on the product (extracting bio-oil is more energy intensive than producing animal feed). Freshwater requirements are believed to be important in both the production and the processing phases of micro algae.

Micro algae aquaculture does not need any strong relationship with the coastline and may be developed almost anywhere, even in landlocked countries. However, it is expected that the Baltic and Arctic basin will have less potential for development of autotrophic production due to cold winter and lesser solar radiation due to distance to equator.

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<sup>27</sup> It has been mentioned that available funding decreased due to several projects failures. However interviewees stressed the fact that the expectations of funding institutions were too high in comparison to the technology maturity.

<sup>28</sup> Shell started large scale algae production projects in 2007 but minimized their efforts in this field again in 2011

## Macro algae

Macro algae farms are expected to develop in cold European waters, from Portugal to the Baltic and Arctic seas. The sector is however in a very early stage and it is not possible to evaluate the level of concentration the sector could achieve in the future. It is expected however that energy companies will try to vertically integrate algae producers and processors.

Interviewees expect that macro algae development will generate a whole new sector with employment tied to the coastline; however high level of automation will lead to a reduction in employment levels. The stock of macro algae growing in farms can also be considered as CO<sub>2</sub> sink and will help lowering the effect of ocean acidification.

The expected developments in this subfunction can possibly influence the future development of the maritime activities (both in terms of synergies and tensions and per sea basins):

- 1.2 Short sea shipping (incl. RoRo): Mild tension in Marine spatial planning – competition for space. Will increase over time with increased intensity of both sectors, this competition is expected to be more stringent in basin where economic activities are more densely concentrated and competition for space is more important (North Sea, Baltic)
- 1.3 Passenger ferry services: Mild tension in marine spatial planning – competition for space, will increase over time with increased intensity of offshore aquaculture, this competition is expected to be more stringent in basin where economic activities are more densely concentrated and competition for space is more important (North Sea, Baltic)
- 2.1 Catching fish for human consumption: Synergy - make use of R&D developments in the processing phase
- 2.2 Catching fish for animal feeding: Synergy - make use of R&D developments in the processing phase
- 2.4 High value use of marine resources: Synergy - make use of R&D developments in processing phase
- 3.2 Offshore wind energy: Tension and Synergy – Marine spatial planning tension – competition for space, which is expected to be more stringent in basin where competition for space is more important (North Sea, Baltic). May increase over time with increased intensity of both sectors, but may decrease with R&D developments on multi-use offshore platforms that combine sectors.
- 3.3 Marine renewables (wave, tidal, OTEC, thermal, biofuels, etc.): Mild tension – Marine spatial planning – competition for space, which is expected to be more stringent in basin where competition for space is more important (North Sea, Baltic). Could increase over time with increased intensity of both sectors. Synergy: both make use of R&D developments on multi-use offshore platforms that combine sectors. Synergy will increase over time.
- 3.5 Aggregates mining (sand, gravel, etc.): Tension – Marine spatial planning – competition for space, which is expected to be more stringent in basin where competition for space is more important (North Sea, Baltic). May increase over time with increased intensity of both sectors. Slight synergy – macro algae installations could be used to aid in the habitat recovery of mined seabed.
- 4.1 Coastline tourism: Tension – Marine spatial planning, competition for space. May also have tension with public (tourist) opinion on spatial quality (appearance of installations). It is expected to be more stringent in dense touristic areas (Mediterranean, Black Sea). Is expected to increase over time with increased intensity of both sectors, but may decrease when public opinion regarding aquaculture offshore is improved. Synergy - when combinations are found through R&D developments on multi-use offshore platforms combining the two sectors.
- 5.1 Protection against flooding and erosion: Synergy - offshore/coastal aquaculture could have a role in wave attenuation and erosion reduction (macro algae). This is expected to increase with development of large-scale aquaculture installations in erosion-sensitive coastal areas, mostly in the Atlantic and the North Sea.

- 5.2 Preventing salt water intrusion and water quality protection: Synergy -. Macro algae will increasingly be used as a mitigating measure to reduce nutrient impacts of aquaculture installations.

## 4 Role of policy

### 4.1 Policy and political relevance

The current political impulse is given on the energy dimension of the micro algae sector in the EU, but also in other countries:

- USA: the Department of Energy has released its National Algal Biofuels Technology Roadmap (US Department of Energy 2010) following the Energy Independence and Security Act of 2007, with the clear objective to reach the industrialisation of micro algae production in a 15 year timeframe<sup>29</sup>. The roadmap addresses the major bottlenecks to overcome before achieving a viable large-scale production of micro algae: algal biology, feedstock cultivation, harvest and dewatering, extraction and fractionation of micro algae but also different downstream issues such as algal biofuel conversion technologies or potential use of co-products. It also highlights the potential of future public-private partnerships in the development of an algae biofuel sector.
- Australia: the Australian government is currently drafting an Energy White Paper which should be released in 2012. It is expected that algal biofuel will be part of the potential pathways as it is already considered in preliminary studies (such as Australian Department of Resources, Energy and Tourism 2010).

Although the Renewable Energy Directive<sup>30</sup> imposes a mandatory 10% minimum target to be achieved by all Member States for the share of biofuels in transport petrol and diesel consumption by 2020, there is no specific focus put on the development of micro algae as a potential biofuel precursor.

### 4.2 Domains for EU policy

Some interviewees commented that the policy focus is currently too much on energy application compared to other applications. The current interest for algae biofuel demonstrators is considered by some interviewees to be premature compared to the current technological potential. They fear that if algae biofuel does not prove to be competitive in the next few years, the interest for micro algae developments will drop as a whole. This would be detrimental to the sector as venture capital might be more complicated to capture for the micro algae sector. It may not be in the remit of the EU to address boom and bust cycles, but interviewees mentioned that EU policies should not favour these cycles. Most interviewees foresee the energy application to be economically viable only in a 10 to 15 years timeframe. They also consider that it would be wiser to focus R&D funding on:

- other promising applications of algae: biomass provider for food and feed industries, green chemistry;
- But also the different technical bottlenecks that are still hindering the cost-effective production of micro algae at an industrial level (mainly photobioreactor development and extraction processes).

It is sometimes considered that some technological routes are not on the radar of policy makers: research on heterotrophic production of micro algae is almost absent from the public research

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<sup>29</sup> The Energy Independence and Security Act of 2007 sets Renewable Fuel Standard (RFS) requiring transportation fuel sold in the U.S. to contain a minimum of 36 billion gallons of renewable fuels, including advanced and cellulosic biofuels and biomass-based diesel, by 2022.

<sup>30</sup> Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC

sphere in Europe when it shares the top of the agenda in other OECD countries (Japan, USA). Macro algae specialists also commented that they felt their part of the sector was not well placed in the political agenda.

- Actions to raise awareness of policy makers, potential industrial clients and the general public would be beneficial to the sector.

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## Annex 2: Stakeholders to be interviewed

Interviews 1 to 8 and 11 to 12 have been completed. Interviews 9 and 10 have been cancelled following comments from DG MARE on a preliminary version.

BLUE GROWTH - DG MARE - SUBFUNCTION PROFILES (WPII) PROPOSAL FOR INTERVIEW LIST							Date
Subfunction:							
Interviewee	Organisation	City/country	Specific theme	Interviewer	Face to face or telephone?	Comments	
1 Jean Guezennec	IFREMER	Brest, France	R&D on biofouling	S. Metz	face to face	held - mixed interview 2.3-2.4	
2 Coentin Renard	Société Gloria Maris Production	Ajaccio, France	Aquaculture producer known to face important biofouling issues	S. Metz	telephone	held	
3 Dr Tim Atack	Vikingfish Farms Ltd; Ardtoe Marine Laboratory	Argyll - UK	R&D aquaculture	S. Metz	telephone	held	
4 Pierre Caleja	Fermentalg	France	Microalgae production - heterotrophic (without light)	S. Metz	telephone	held	
5 Dr Martin Ecke	Roquette Klötze GmbH & Co. KG	Germany	Microalgae production - photobioreactor	S. Metz	telephone	held	
6 Aad Smaal	Institute for Marine Resources and Ecosystem Studies	The Netherlands	RAS technologies	H. Hulsman	telephone	held	
7 Dr. Willem Brandenburg	Plant Research International - Wageningen University	Netherlands	R&D micro- and macro-algae aquaculture	H. Hulsman	face to face	held	
8 Pr Jérémy Pruvost	GEPEA - Université de Nantes	France	Marine bioprocesses	S. Metz	telephone	held	
9 Carlo Badinotti	Badinotti Italia	Italy - Slovakia	Biofouling + progress in offshore designs (Med.)			cancelled	
10 Bente Lund Jacobsen	MøreNot AS	Norway	Biofouling + progress in offshore designs (Atl.)			cancelled	
11 Álvaro Naranjo Villalonga	BTM (Bioteconología de Microalgas)	Spain	Microalgae production - photobioreactor	S. Metz	telephone	addition - held	
12 Pål Bakken	Seaweed Energy Solutions AS	Norway	Macroalgae for energy	S. Metz	telephone	addition - held	



## Annex 3: Impact matrix of the medium-term and longer-term developments

Table A1: Impact matrix of the medium-term and longer-term developments

Function	Indicators	Bal- tic	North Sea	Medi- terr.	Black Sea	Atlan- tic	Arc- tic	Outer most
1. Economic impacts	Market value		-	-	-	-		-
	GVA		+	+	+	+		+
2. Employment impacts	Employment		0(+)	0(+)	0(+)	0(+)		0(+)
3. Environmental impacts	CO <sub>2</sub> levels		0/+	0/+	0/+	0/+		0/+
	Nutrient / water quality		-/+	-/+	-/+	-/+		-/+
	Energy requirement		-	-	-	-		-
	Water requirement		-	-	-	-		-
4. Other impacts								

*Explanation:*

*++ = Strong positive impact expected*

*+ = Considerable positive impact expected*

*0 = Negligible impact expected*

*- = Considerable negative impact expected*

*-- = Strong negative impact expected*



## Annex 4: Impact, synergies and tensions matrix

Function affected	Sub-function affected	General	Bal-tic	North Sea	Medi-terr.	Black Sea	Atlan-tic	Arc-tic	Outer most
1. Maritime transport and shipbuilding	1.1 Deepsea shipping	0	0	0	0	0	0	0	0
	1.2 Shortsea shipping (incl. RoRo)	-	--	--	-	-	-	0	-
	1.3 Passenger ferry services	-	--	--	-	-	-	0	-
	1.4 Inland waterway transport.	0	0	0	0	0	0	0	0
2. Food, nutrition, health and ecosystem services	2.1 Catching fish for human consumption	0+	0+	0+	0+	0+	0+	0	0+
	2.2 Catching fish for animal feeding	0+	0+	0+	0	0	0+	0	0+
	2.3 Growing aquatic products								
	2.4 High value use of marine resources (health, cosmetics, well-being, etc.)	0+	0+	0+	0+	0+	0+	0	0+
	2.5 Agriculture on saline soils	0	0	0	0	0	0	0	0
3. Energy and raw materials	3.1 Oil, gas and methane hydrates	0	0	0	0	0	0	0	0
	3.2 Offshore wind energy	0+	++	++	0+	0+	0+	0	0+
	3.3 Marine renewables (wave, tidal, OTEC, thermal, biofuels, etc.)	+	++	++	+	+	+	0	+
	3.4 Carbon capture and storage	0	0	0	0	0	0	0	0
	3.5 Aggregates mining (sand, gravel, etc.)	-	-	-	-	-	-	0	-
	3.6 Mineral raw materials	0	0	0	0	0	0	0	0
	3.7 Securing fresh water supply (desalination)	0	0	0	0	0	0	0	0
4. Leisure, working and living	4.1 Coastline tourism	0 -	0 -	0 -	-	-	0 -	0	0 -
	4.2 Yachting and marinas	0	0	0	0	0	0	0	0
	4.3 Cruise including	0	0	0	0	0	0	0	0

Function affected	Sub-function affected	General	Bal-tic	North Sea	Medi-terr.	Black Sea	Atlan-tic	Arc-tic	Outer most
	port cities								
	4.4 Working	0	0	0	0	0	0	0	0
	4.5 Living	0	0	0	0	0	0	0	0
5. Coastal protection	5.1 Protection against flooding and erosion	0+	0+	++	0+	0+	++	0	0+
	5.2 Preventing salt water intrusion and water quality protection	+	+	+	+	+	+	0	+
	5.3 Protection of habitats	-/+	-/+	-/+	-/+	-/+	-/+	0	-/+
6. Maritime monitoring and surveillance	6.1 Traceability and security of goods supply chains	0	0	0	0	0	0		0
	6.2 Prevent and protect against illegal movement of people and goods	0	0	0	0	0	0		0
	6.3 Environmental monitoring	0	0	0	0	0	0		0

*Explanation:*

*++ = Strong positive impact on other subfunctions/sea basins expected*

*+ = Considerable positive impact on other subfunctions expected*

*0 = Negligible impact on other subfunctions/sea basins expected*

*- = Considerable negative impact on other subfunctions expected*

*-- = Strong negative impact on other subfunctions expected*



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