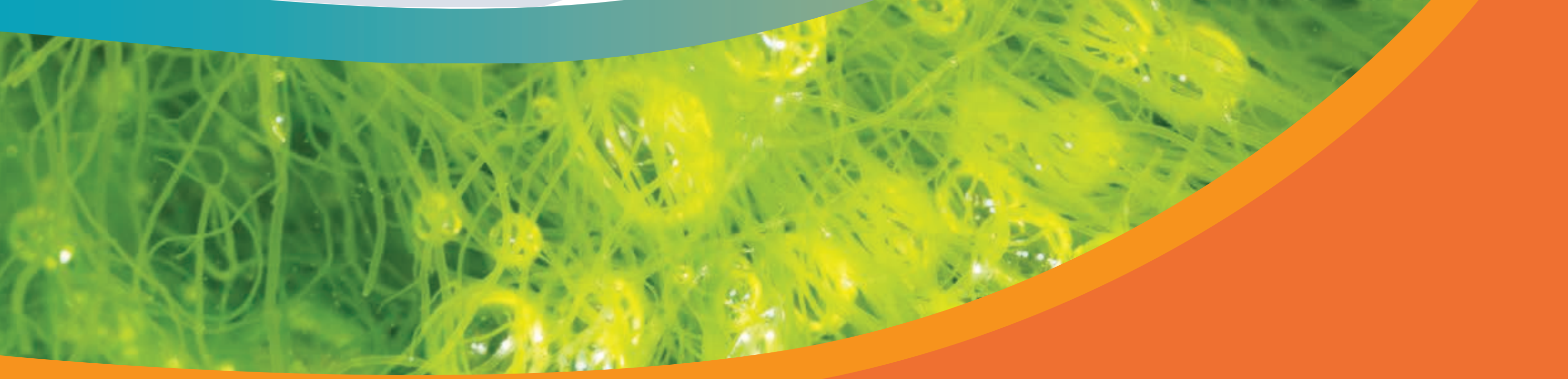
EnAlgae

collaborate innovate communicate

Summary of results and policy recommendations for cultivation of algae in North West Europe for energy production (and potentially other non-energy products)

Report WP2A12.06



Energetic Algae ('EnAlgae')

Project no. 215G

Public Output

Output WP2A12.06 – Summary of results and policy recommendations for cultivation of algae in North West Europe for energy production (and potentially other non-energy products)

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INTERREG IVB

Summary of results and policy recommendations for cultivation of algae in North West Europe for energy production

Executive summary

For four years several groups in EnAlgae have collected data and information on factors influencing micro and macro algae production in North West (NW) Europe. These factors include academic and industrial research, LCA and sustainability, macro- and business economics, political landscape, regulatory and licencing framework.

All the factors strongly impact on the development rate of algae cultivation technologies, and can slow down or even stop their further development. Action 12 studied how these factors influence the development of four promising algae cultivation technologies, which factors are forming barriers in the further development of these algae cultivation concepts, and what actions are needed to lift these barriers and accelerate development. These actions were finally translated into policy recommendations for NW European policy makers. The analysis used the "Technological Innovation System" analysis (TIS) method, and to achieve optimal results the analysis was performed at country-level.

The four algae cultivation concepts that were studied, two for macro and two for micro algae, were pre-selected by the nine pilot technology developers and then selected via SWOT analysis of 20 different algae cultivation systems. These four were considered to be some of the most promising concepts for production of energetic algae in the NW European region, although these concepts use core technologies that are still currently in a pre-developed phase. Throughout, the analysis took account of the early phase of development of all the studied concepts and was adapted accordingly.

The study analysed the performance of seven universal system functions that are catalytic for the development of the studied algae cultivation concepts, and subsequently rated them. The four case studies revealed that each studied country of NW Europe supports and influences the development of algae cultivation innovations in a special way. A spider diagram was produced that showed the seven system functions examined along with the allocated grades of the algae cultivation technologies studied.

Where a system function had a low grade, as shown in the spider-diagram, this was targeted for recommendations to improve performance, and thus accelerate development of studied algae cultivation concept. The recommendation list below reflects the low performance of some of the functions of the case studies and works towards removing the identified barriers and also creating drivers for accelerating development of algae production in NW Europe.

A short list of policy recommendations for algae development in NW Europe:

1. Increase competitiveness of microalgae cultivation and processing technologies;
2. Build open access pilot facilities for developing and testing algae cultivation and processing at commercially relevant scales;
3. Develop tools to create sustainable algae value chains;
4. Increase transparency of societal and market benefits and costs of algae;
5. Produce, maintain and supply technical and business competencies supporting algae cultivation and biorefining;
6. Introduce a strong and reliable policy and regulatory framework supporting algae commercialization.

Summary of results and policy recommendations for cultivation of algae in North West Europe for energy production

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1 Study background

EnAlgae partners have collected data and information on factors influencing micro and macro algae production in NW Europe. These factors include levels of academic and industrial research, LCA and sustainability understanding, macro- and micro- algae business economics, market product reviews, the political landscape, and regulatory and licencing frameworks. All the factors strongly impact on the development rate of algae cultivation technologies, and can slow down or even stop future development.

Through discussions with EnAlgae partners a SWOT[1] analysis of 20 promising algae cultivation systems and concepts were performed. From this assessment four cultivation concepts were chosen for further analysis. Although these concepts use core technologies that are still currently in a pre-development phase, they are considered promising concepts for production of energetic algae in NW Europe.

The four concepts were further investigated using "Technological Innovation System" analysis (TIS[2]) which to achieve optimal results was performed at country-level. TIS analysis allows a range of functions influencing the development of the promising algae cultivation concepts to be studied, identifying which factors are forming barriers to the further development of the cultivation concepts, and what actions are needed to lift the barriers and accelerate development. Throughout the analysis the early phase of development of all the studied systems and concepts was considered and steered the development of actions. Finally, the identified actions were translated into policy recommendations for NW European policy makers.

2 System analysis and identified barriers for algae

The study analysed the performance of seven universal system functions that are catalytic for the development of the studied algae cultivation concepts, and subsequently rated the functions in a scale from 1 to 5. When a system function was found to be a major driver in the further development of the studied algae cultivation concept, it was given a grade 5 (maximum). At the other end of the scale, if a system function acted as a major development obstacle it was given a grade 1 (minimum).

The two microalgae case studies were:

- Cultivation of microalgae in the UK for energy production (and potentially other non-energy products) by using photobioreactor (PBR) technologies and recycling nutrient-rich industrial wastewater and industrial CO_2;

- Cultivation of microalgae in the Netherlands for energy production (and potentially other non-energy products) by using raceway pond technologies and by recycling nutrient-rich industrial wastewater.

[1] Strengths, Weaknesses, Opportunities and Threats (SWOT)
[2] http://www.innovation-system.net/tis-literature/

The two macroalgae case studies were:

- Marine cultivation of macro-algae in France for energy production (and potentially other non-energy products) by using longline technologies;

- Marine cultivation of macro-algae in Ireland for energy production (and potentially other non-energy products) by using longline technology in an Integrated Multi-Trophic Aquaculture (IMTA) concept.

The four case studies revealed that each NW European country supports and influences the development of algae cultivation innovations in a different ways. The results from the analysis of each case are summarised below. Figure 1 summarises the findings from grading the performance of 7 functions.

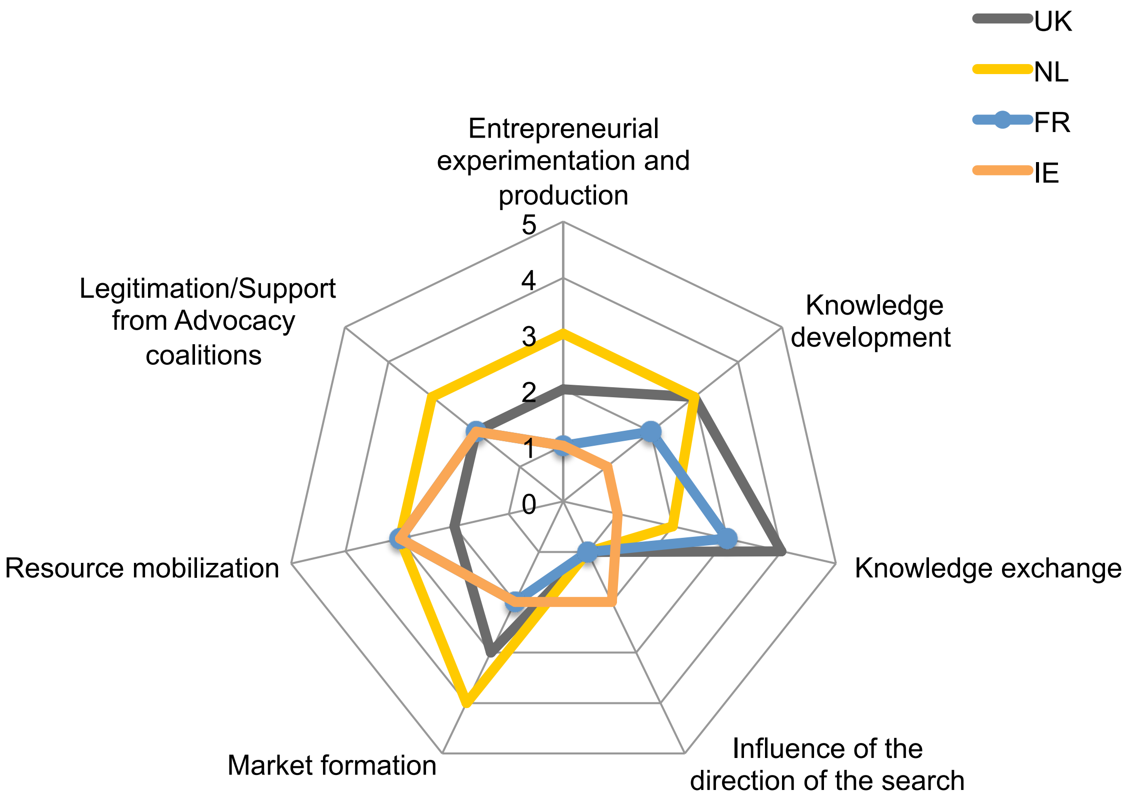

Figure 1: *Spider-diagram summarising findings from grading performance of 7 functions affecting the deployment of the scoped technology.*

Based on the analysis of the 7 functions (Fig.1), two lists of recommendations for action were created; one for micro- and one for macro- algae. The lists reflect the low performance of some of the functions of the case studies and works towards removing the identified barriers and also creating drivers for accelerating development of algae production in the country of reference.

The development phase of the technology defines which functions are the most influential in future development and deployment of the scoped technology, and as a result which policies should be prioritised. The four scoped technologies are considered to be in a pre-development phase[3], this is based on the fact that there are multiple working prototypes but no commercial applications have been established, although some interest from industry has been noted. Because of the current phase of development, not all functions are equally influential in further development of the scoped technology. For a system in a pre-development phase, the most important functions are: Knowledge development; Knowledge exchange; Guidance of search; and Resource mobilization.

Briefly, the actions denoted with a diamond (♦) symbol are considered priority recommendations to catalyze further development of the scoped technology in the NW Europe. On the other hand, the actions not signposted by a diamond are actions of secondary priority; although not critical for the development of the scoped technology at this phase, these calls for action may also a positive effect in the development of the scoped technology.

3 Policy recommendations for microalgae

Recommendation 1: Increase competitiveness of microalgae cultivation and processing technologies

♦Provide targeted funding of R&D programmes of microalgae cultivation and processing technologies

There is still a need for research aiming at cutting production, harvesting and processing costs of microalgae. Research demand includes funding academic research primarily in 1) biotechnology for developing competitive and strategic microalgae technology platforms, and 2) engineering fields like bioprocess engineering and environmental engineering for developing, optimising and integrating processes for production, harvesting, biorefining and conversion of microalgae to end-products of commercial interest.

With this in mind, a selection of microalgae biotechnological platforms most suitable for commercial exploitation should be selected out of the pool, and subjected to intensive study. Such selection requires input from different stakeholders, including technology developers, industrial associations, and policy makers. But such a selective and coordinated approach is crucial for deepening the understanding of microalgae cultivation and processing and also accelerating the development of knowledge at this early stage.

There are currently several EU R&D projects targeting algal biofuel markets, covering microalgae cultivation, biorefining, conversion to biofuels, and also targeting the scoped technology. There are also some EU R&D projects focusing on algal bioproducts, other than energy, such as high value chemicals. Mainly these project calls target academics and companies, creating incentives and supporting early stage technology transfer. However, the cost of microalgae cultivation is still prohibitive, which is reflected also in the reluctance of the large enterprises to engage major private investments in microalgae innovation projects, and bring them to the market. Funding Strategic R&D projects that aim at lowering the production costs of algal biofuels and non-energy products is expected to directly and indirectly improve the marketability of microalgae, increase entrepreneurial experimentation and production, including attracting more large enterprises.

[3] http://www.innovation-system.net/tis-literature/

♦**Prioritise funding R&D on handling, biorefining and processing microalgae to non-energy microalgae products instead of energy products**

There is a clear need for funding R&D projects that scope microalgae-from-waste added-value products, as this will bring a strong driving force for microalgae entrepreneurship experimentation and market development. This is of strategic importance since technologies for microalgae harvesting, handling, biorefining and processing are still far from competitive, and microalgae cultivation technologies were found more developed than microalgae biorefining and processing technologies.

♦**Fund innovation projects on biorefining microalgae, co-product development, and microalgae from waste**

More public-funded research and innovation projects are needed for 1) developing knowledge on biorefining microalgae and symbiosis concepts, including processing technologies and cost/benefit analysis, 2) bioprospecting and developing high added-value products in conjunction to energy co-products, and 3) connecting businesses producing wastewater rich in mineral soluble nutrients[4] and industrial CO_2 emitters with knowledge developers of microalgae cultivation, microalgae biorefining and conversion technologies. Such effort will overall bring algal biorefineries and algal energy closer to the market.

Each Research and Innovation (R&I) project should include a budget for disseminating activities to the microalgae community. These dissemination activities should clearly communicate the associated economic and societal benefits and costs of the scoped technology, and by these activities will effectively propel knowledge exchange, entrepreneurship experimentation, and mobilise additional resources from private funds.

Recommendation 2: Build open access pilot facilities for developing and testing microalgae cultivation and processing at commercially relevant scales

The research showed that microalgae cultivation technologies for energy purposes have been developed up to pilot scale, yet the technology has many technical, energy efficiency and economic constraints to resolve before it proves itself, especially if energy from microalgae is the target product. Testing the microalgae cultivation technologies at commercially relevant scales is a prerequisite for enhancing knowledge through research and learning-by-doing, as in fact technical, energy efficiency and economics parameters are profoundly affected by the scale of the technology.

♦**Build open access pilot-scale facilities for microalgae cultivation**

For better "value-for-money", where money is the capital investment for building assets for testing microalgae cultivation and value is the returned-to- society developed knowledge and entrepreneurial experimentation, it is very important to build technological hubs that host processing facilities which are accessible and flexible in operation. Such facilities need to be relevant to microalgae, modular and scalable. By accessible it is meant that the facilities are built and managed so that various actors, for example RTD, enterprises and entrepreneurs, can have the ability to use these facilities for testing their technologies at large scale and also for developing complementary new technologies.

[4] Primarily nitrogen and phosphorus

♦ **Develop technology hubs and centres of excellence for microalgae**

Ideally these hubs could shape into centres of excellence, which in addition to facilities, offer competence and expertise to developers and entrepreneurs. The development of user-friendly and accessible pilot and demonstration facilities for microalgae cultivation supported by expert workforce, will allow not only entrepreneurial experimentation and knowledge development, but also will allow more reliable estimation and better understanding of the benefits and costs of the technologies.

Recommendation 3: Develop tools to create sustainable microalgae value chains

♦ **Secure network activities supporting microalgae**

There is an identified need for coordinated networking activities for bringing closer industrial CO_2 and wastewater handling actors with microalgae cultivation actors, and fuel producers or fuel blenders. The research showed that not all NW European countries had national microalgae networks. For example in the UK there are five relevant national microalgae networks supporting development of complete microalgae value chains, including algal biofuels. On the other hand, in the Netherlands no microalgae network or sub-network was found, other than R&D projects that, by definition, are time restricted. Also on a European level, EABA organises networking activities for microalgae producers and biofuel end-users at European-level. However EABA[5] has no country contact points that could form local working groups or hold national or regional networking events. Also, a recommendation directed to the existing networks is to collaborate more for delivering networking activities to the value chains associated with the scoped technology.

Networking actors across the innovation and value chain, both nationally and internationally, is crucial for developing complete value chains and exchanging knowledge, which will also induce development of new knowledge in a synergistic fashion, e.g. connecting actors from wastewater production and handling, industrial CO_2 emitters, microalgae cultivation, microalgae processing, and product developers. Given the current phase of development of the scoped technology there is a strategic gap to be filled for a microalgae network that will support developers and entrepreneurs to access pooled scientific and learning-by-doing knowledge as well as other resources across the innovation and the value chain. The networks, as well as matchmaking and knowledge exchange activities, should focus on 1) probing the interests of existing businesses to integrate new microalgae technologies in their business models, 2) engaging with large enterprises, 3) develop open innovation events where companies with unused patents could share them to benefit from win/win collaborations, 4) showcasing benefits and success stories from projects incorporating microalgae biorefining and co-product development and microalgae-from-waste. Such a network will be the platform to assemble competitive complete value chains surrounding the scoped technology and advance microalgae out of the labs and into the market. Some of these activities are already in the portfolio of activities of the existing networks; however the scope of the microalgae networks should be better adjusted for microalgae bioremediation value chains.

Recommendation 4: Increase transparency of societal and market benefits and costs of microalgae

While the microalgae industry has made considerable steps in development of microalgae cultivation systems facilities pilots using industrial wastewater rich in soluble nutrients and industrial CO_2, and integrated them in innovative industrial symbiosis projects, it is still considered as being at a nascent

[5] European Algae Biomass Association

stage. There is no clear view of what the main benefits are and costs associated with the best available microalgae cultivation technologies and microalgae (energy) products.

♦Build tools to benchmark economic and societal benefits and costs of the microalgae cultivation technologies

To be able to optimise microalgae cultivation technologies and assess their environmental and economic performance, a series of systematic methodologies assessing the associated benefits and costs in a life-cycle are essential. This is of strategic importance for example in cases where "waste" CO_2 and mineral nutrients (e.g. nitrogen and phosphorus), in the form of industrial wastewater and industrial CO_2, can be upcycled for production of added value products, and thereby these technologies will play an intrinsic part in the circular economy. A first effort was undertaken in EnAlgae project with the development of the Decision Support Toolset (DSTs); however building upon and expanding these tools and underpinned knowledge is of strategic importance. Dissemination strategies and activities should be secured once the tools are released, and development projects are terminated, so knowledge does not slowly fade out and get lost (see also recommendation 1.3).

If in addition to the tools, the results produced are translated in a manner that allows comparison of findings and benchmarking setups, this will help align expectations and visions surrounding microalgae cultivation technologies. Potentially, identification of benefits and costs will help in firmly positioning algae cultivation technologies in agro-technology and aquaculture sectors, which is not the case currently. These tools should be preferably used on large-scale projects, because experience has shown that environmental and economic performance is greatly affected by project scale. This is also one more reason why the nascent industry has a need for accessible demo facilities for testing and building business cases (see also recommendation 2).

♦Found effective national advocacy coalitions

The lack of effective national associations for microalgae, leaves a big gap in the legitimation process of the microalgae products and the associated production technologies, including the cases that combine wastewater treatment and reuse of industrial CO_2 with production of microalgae and algal biofuels. As a result, competitively sustainable technologies and successful business models are not effectively supported and highlighted, which in return affects associated entrepreneurship experimentation, market development, and strategic policy development. National advocacy coalition featuring networking services at national level, as described in recommendation 3, would be very beneficial.

Facilitate un-restricted and un-obstructed dissemination of research and innovation findings

Routes for results dissemination of publically-funded research and innovation projects need to be extended to encourage authors to publish findings and results in open access scientific articles and also allocate an economic budget for associated publication costs, and also support digitisation of world academic libraries and make them accessible to all users. Finally, microalgae networks and associations should also be in a good position to develop networking activities for knowledge exchange and open access innovation. Increasing impact of disseminated research on innovation development and deployment and transparency of R&D sector is very important for accelerating deployment and taking up of microalgae technologies.

An example of a knowledge product that can strategically increase microalgae's value proposition as an environmental remediation service and can play a vital role in the further development of the scoped technology, is on-line EnAlgae GIS tool that belongs to the EnAlgae DSTs[6]. The GIS tool maps availability and quality of supply of “waste” resources (industrial CO_2, organic nutrients, waste heat), locally, all year round, without disturbing existing markets, and covers the NW Europe. Such information enables building sustainable business models that combine environmental bioremediation with microalgae production. As a result, it is of crucial importance that products like these are disseminated effectively to reach the target users beyond the timeline of the R&D project that developed it.

Recommendation 5: Produce, maintain and supply technical and business competencies supporting microalgae cultivation and biorefining

In recommendation 2.2 a need was suggested for centres of excellence around algae cultivation technologies. In addition to the benefits listed previously, the development of such technological hubs or centres of excellence will have dual impact on microalgae expertise and competencies: 1) it will help attract and geographically accumulate workforce and students holding competencies and expertise around microalgae cultivation, wastewater treatment, and microalgae processing, and 2) it will help retain and prevent dilution or loss of competencies, something that happens for example in academia when microalgae R&D projects are not renewed. The latter is particularly critical for algal biotechnologies because of the immaturity of the science.

Support bio-entrepreneurship education

Because business ventures using microalgae cultivation technologies are underpinned by complex and quickly-developing bioscience and bioengineering e.g. biorefineries and industrial symbiosis, but also surf across fast-moving markets and changing policies and regulations, a new specialised field has emerged to meet these new demands, called bio-entrepreneurship. Many pioneer countries in the fields of bioengineering and biotechnology have introduced such educational programs, including the Netherlands and the UK. Setting up bio-entrepreneurship programs and courses 1) helps new entrepreneurs understand knowledge-based business, bio-innovation and bioeconomy better, and 2) develop bio-entrepreneurial skills into process developers and engineers. Both objectives will facilitate bridging the language and trust void space that often builds between entrepreneurs and process and technology developers and it will result in boosting microalgae business development, new technology integration, and business sustainability.

♦Secure an even flow and supply of technically-skilled microalgae workforce

Apprenticeship or internship programs help workforces develop competencies and expertise in industrial environments, something that the nascent microalgae industry finds very important. Apprenticeships will have to evolve in line with the needs of the market, starting at small scale, as currently the market is in a nascent stage.

Although many NW European universities have accumulated expertise and competencies from R&I activities around microalgae cultivation, these are typically constrained by application scale. Laboratory processing equipment that is used in education (university etc.) is limited by size from laboratory to pilot scale in best-case scenarios. However, (nascent) industry has an increasing need for technical expertise for larger scale projects, which cannot be obtained solely from available universities, RTDs and technical training schools. There is already an identified gap between what skills new workforce possesses and what industry needs for expanding activities, integrating new microalgae technologies, and improving

[6] http://ixion.bcu.ac.uk/

sustainability of business. This gap needs to be covered in time by securing that microalgae is always included in and actively supported by educational schemes covering the industrial biotechnology sector in NW Europe.

Recommendation 6: Introduce a strong and reliable policy and regulatory framework supporting microalgae commercialisation

Some national policies of NW European countries support microalgae exploitation as an important biomass feedstock for the biobased economy. However, many other national and also EU policies do not clarify status and role of microalgae biomass e.g. energy policies. Moreover, few EU and national regulations have product standards for microalgae biomass and ingredients.

♦Include microalgae in circular economy policies

A recommendation, under the circular economy framework[7], is to incentivise strategies for recycling industrial side-streams containing soluble mineral nutrients, like nitrogen and phosphorus e.g. from fermentation, food production, aquaculture, or anaerobic digestion activities, and also reusing captured fossil/renewable CO_2 produced by industrial activities, e.g. power plants, CHP, food fermentation etc., to "feed" microalgae production. Such material exchange processing lines are cornerstones in industrial symbiosis and (bio)refinery projects. Economic incentives for linking industries for material and energy exchange, e.g. industrial symbiosis and biorefineries, could be facilitated by for example making it a priority in EC R&D programmes and regional governments hosting industrial parks.

Regional governments could incentivise development of industrial symbiosis projects using microalgae cultivation technologies in their area by acting as a catalyst to development of favouring business plans and by attracting funding and competencies to the area.

♦Clarify status of microalgae-from-waste and their downstream products

By clarifying the state and the role of microalgae biomass and their product derivatives, regulations inhibiting their marketability will be identified and replaced. This would unlock doors to a range of new markets, release public and private investment and increase the legitimacy of algae. Under current EU regulations, microalgae produced from waste resources, as well as their associated microalgae products, are not clearly supported by deployment incentives and quality standards. But the development of markets for non-energy algal products, like food, feed, high value chemicals, and remediation, will most likely precede those of algal fuels. For example, microalgae produced by recycling CO_2, and soluble mineral nutrients can currently be used for very limited applications, while there is no clear provision for using microalgae-from-waste in food and feed products[8]. This lack of regulatory provision creates reluctance in the market to invest in technologies of biological industrial wastewater treatment that produces biomass with questionable value in the market.

A first action would be a thorough safety and risk assessment of microalgae-from-waste production methods and associated products, followed by establishing a series of Best Available Techniques (BATs) and norms (i.e. European Standards), potentially in collaboration with international certification organizations. Such coordinated action will define risks and benefits of microalgae-from-waste products

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[7] http://ec.europa.eu/environment/circular-economy/index_en.htm
[8] Food and feed market is very promising for using microalgae extractives, while the microalgae residues can still be used for energy production.

and the scoped production technologies, and underpin development of confident regulations, which will influence market development and increase legitimisation of microalgae-from-waste products.

Define LCA methodology and carbon accounting of microalgae biorefining

Expanding recommendation 6.2 and also recommendation 4.1, clarification is required for carbon accounting systems used for algal renewable fuels[9]. Autotrophic microalgae are photosynthetic organisms that do not require agricultural land (although they do require industrial land, which is not negligible depending on cultivation technology), and can act both as microbial factories for converting soluble mineral nutrients (e.g. nitrogen and phosphorus) into a refined product and as biomass feedstocks. In either case, when more than one product category is produced from microalgae, e.g. food, added-value products, transport fuels, heat, it is not straightforward a) how primary and secondary products are defined, b) what LCA methodologies should best be applied and c) how carbon emissions cultivation and processing are allocated to algal products. Clarification of the LCA aspects for microalgae cultivation and biorefining can influence market and technology development as the large amount of energy required for microalgae cultivation potentially impact the sustainability credentials of the fuels and products produced.

Establish stable strong advanced renewable fuel policies that support microalgae

The rapid alteration of the EU regulations for renewable fuels creates long-term uncertainty for investors and can undermine entrepreneurial experimentation. Establishment of stable trajectory targets, support measures and mechanisms for renewable fuels is an important factor for the deployment of novel technologies.

In the recent amendment of the EU RED[10], microalgae cultivate “on land in ponds or photobioreactors” were included in a list of fuels and feedstocks under Annex IX, eligible for double-counting against the overall renewable energy transport target and for contributing towards a separate “advanced” fuel sub-target. The Annex also includes CCU (Carbon Capture Utilization) technologies (whereby renewable energy is used for processing) which could be applicable to some algal cultivation technologies, including the scoped technology. This is a significant step in placing microalgae in the EU renewable energy map. However, further clarification is required for how algal technologies are treated.

For the first case where microalgae are clearly mentioned, there is no reference to whether it is only fuels from autotrophically cultivated microalgae that are supported as advanced fuels. From the two cultivation methods described - and on account that a cap has been placed on fuels derived from crops (including sugars) - it is implied that it is only fuels from autotrophic microalgae that would be considered as “advanced”. However, this is not clear. Moreover, for instances where fuels are produced from algal CCU technologies, it is not obvious whether the microalgae or the CO_2 would be considered as the feedstock for the process. If it is the latter this could have an important bearing on the technology, as the fuel would only be eligible for support as an advanced fuel if the process energy used is renewable. Better clarification will make policy stronger and the investors and the market more confident of what is the direction of the search in CCU and algal energy production.

[9] This policy is relevant for algae produced by renewable CO_2, e.g. food fermentation, and not from e.g. co-firing/coal/gas power plants or CHP, etc.
[10] https://ec.europa.eu/energy/en/topics/renewable-energy/renewable-energy-directive

The advanced fuel sub-target under the RED is set at just 0.5% of final energy consumption in road and rail transport[11]. The target is only voluntary, with member states able to set a lower target if so desired, and is also only set to 2020. Beyond 2020 and to 2030 the "policy framework for climate and energy" outlines a new set of ambitious targets for renewable energy and GHG emissions; however beyond 2020 the framework introduces targets that are binding only at EU level, and not at country level, and also removes targets for individual sectors, e.g. transport targets. It is more likely that mandated, ambitious targets for transport and long-term trajectories will be required to provide the necessary certainty for investment in advanced biofuels given the policy and market instability faced by first-generation biofuel investors.

Support carbon recycling through CCU technologies including microalgae

The upcoming circular economy directive should also highlight strategic importance and value of CCU technologies, compared to the competitive Carbon Capture and Storage (CCS) technologies. CCU technologies, recycling CO_2 for production of added-value products and algal fuels, are highly ranked by EU waste policy, and they fall under the EC KETs. At the same time, CCS technologies, acting as a carbon sink, are enjoying both political and funding support by national governments and the EU; CCS technologies play a strategic role in the EU energy policy. Policies reflecting visions and expectations for each of the two technologies at high level are required, if CCU technologies, for example the scoped technology, are to be further developed and deployed for fuel production in the future.

♦Introduction of a CO_2 framework supporting microalgae

There is a need for a CO_2 framework (national or at EU-level) that contains mandates and economic and other incentives supporting development and deployment of technologies that upcycle CO_2 from both fossil and renewable sources for production of energy, materials and food. Examples for better regulation of CO_2 emissions incldue introduction of a carbon tax and a functional EU ETS, but also funding relevant R&I projects for CCU for microalgae production.

Enlist microalgae production activities in the EU IED Directive

Under the The Industrial Emissions Directive - IED[12] (previously Integrated Pollution Prevention Control Directive, IPPC) and other EU environmental protection measures, large scale algal production facilities would be subject to high levels of industrial permitting. However, such industries are not specifically listed in the IED legislation or guidance issued to national governments. One recommendation could then be that the IED Directive and its implementing requirements is amended to specifically include microalgae production projects and thereby provide greater clarity for producers and regulators, streamline procedures and also ensure a harmonised approach to permitting across Europe.

Integrate the planning process with different environmental permits

The integration and streamlining of administrative procedures supports new start-up operations that are exploiting microalgae, as the integrated procedures are easier and quicker and thereby cheaper. In the UK for example environmental permitting is not integrated with building permissions, and different procedures have to be followed in each case, involving different levels of agencies (national, regional and local). Local authority discretion in spatial planning and decision making is a feature of many European

[11] http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32009L0028
[12] http://ec.europa.eu/environment/industry/stationary/ied/legislation.htm

states, including the UK, the Netherlands, Germany, and Ireland. However, national governments could provide more planning incentives for algal production through incorporating it into their strategic developmental objectives, through for example spatial planning, and parallel energy or industrial policies.

4 Policy recommendations for macroalgae

Recommendation 1: Increase competitiveness of sustainable macroalgae cultivation and processing technologies

♦Provide targeted funding development programmes for macroalgae (co-) cultivation and processing technologies

There is an ongoing need for further development and process intensification aimed at cutting costs of macroalgae production, logistics, harvesting, handling and processing. Demand includes funding development and engineering primarily in 1) mechanical equipment design for seeding, production, harvesting and logistics, 2) developing low cost macroalgae storing and handling (e.g. drying), and 3) chemical and bioprocess engineering fields for developing, optimising and integrating processes for production (nursery), seeding, and also macroalgae biorefining for conversion of macroalgae to fuels, chemicals, and materials. There are currently some national R&D projects targeting macroalgae breeding, ecology and cultivation and macroalgae chemistry for product development, and also EU-funded R&D projects targeting macroalgae cultivation, biorefining, conversion to fuels and plastics, and bioprospecting of added-value products in macroalgae, e.g. pharmaceuticals. Mainly the calls target academics and companies, including SMEs, creating incentives and support for early stage technology transfer. However the cost of products based on macroalgae is still largely commercially prohibitive, which is reflected in the reluctance of large enterprises to place major private investments in macroalgae innovation projects and bring products to market. Funding strategic R&D projects that aim at lowering the production and handling costs of algal biofuels and other non-energy products is expected to directly improve the marketability of macroalgae, increase investments, entrepreneurial experimentation and production, including attracting more large enterprises.

One more recommendation is that basic and applied research activities focusing on plant breeding, biotic interactions, plant metabolism and plant pathology, marine ecology protection and biodiversity have to be funded along with cultivation and processing technologies. Intensive aquaculture of macroalgae at increasing scales, e.g. similar to fish and mollusc aquaculture could potentially disturb the balances of marine ecosystems, causing environmental implications e.g. in ways similar to those found in the land based arable agriculture sector. Although the intensity of activities and scales of cultivation at sea is currently small and cannot be compared to those of land agriculture, care should be taken to safeguard the natural marine ecosystems from e.g. 1) uncontrolled invasion of newly introduced species or their pathogens to the natural marine environment and loss of biodiversity (impacting also established macroalgae harvesting artisan businesses), 2) the release of secondary metabolites from macroalgae, potentially having toxic or ozone-depletion attributes (e.g. iodine and bromium compounds). On the development level, cross-breeding macroalgae for increasing biomass and target product yields should be also supported. For example, Ireland and France appeared not to have invested in investigating environmental issues associated with macroalgae aquaculture, evident from the number and type of current national R&D projects, which demonstrates the early stage of development of the sector.

♦Prioritise funding innovation projects on biorefining macroalgae and co-product development of energy and non-energy macroalgae products

There is a strong need for funding more research and innovation (R&I) projects that consider added-value macroalgae products, because this will be a strong driving force for macroalgae entrepreneurship experimentation and market development. Because technologies for macroalgae cultivation, harvesting, handling, transporting, storing and biorefining are still expensive, high value product markets are more likely to develop first. However, currently there is little knowledge at production level in converting macroalgae to high added-value products. Identified commercial activities either use the whole macroalgae plant for a single use, or they use the plant for a primary product with no market for the residues. For example food products and ingredients for cosmetics and soil conditioners are the main non-energy macroalgae products. Energy and fuels (bioethanol, biogas) from macroalgae are still in early research phases, although macroalgae has been tested in large scale AD technologies in France.

More public-funded R&I projects are needed for 1) developing knowledge on biorefining macroalgae and co-product development, including processing technologies and cost/ benefit analysis, 2) bioprospecting and developing high added-value products (in conjunction with energy co-products) 3) integration of macroalgae cultivation in industrial symbiosis concepts, e.g. IMTA[13] as well as wind farms. In the latter case cost/ benefit analysis should also be included. Projects like the ones covered above will be able to bring algal biorefineries and algal energy closer to the market.

More importantly, each R&I project should include a budget for disseminating information to the macroalgae community that will effectively propel knowledge exchange, entrepreneurship experimentation, and mobilise additional resources from private funds. The dissemination activities should also communicate the associated economic and societal benefits and costs of macroalgae cultivation technologies.

Recommendation 2: Build open access pilot facilities for developing and testing macroalgae cultivation and processing at commercially relevant scales

While IMTA concepts were found to be at very early stage and have not been taken up by industry yet, macroalgae cultivation on marine longlines is slightly more advanced in some cases, e.g. in France. However, the technology still has many technical and economic constraints to resolve before it proves itself, especially if energy is the primary product. Developing and testing the macroalgae cultivation technologies at pilot scale is a prerequisite for enhancing knowledge through research and learning-by-doing, as in fact technical, energy efficiency and economic parameters are profoundly affected by the scale of the technology. However no research facilities were found at commercially relevant scales, in e.g. Ireland or France, that were accessible.

♦Build open access pilot-scale facilities for macroalgae cultivation

For better “value-for-money”, where money is the capital investment for building assets for testing macroalgae cultivation technologies and value is the returned-to-the-society developed knowledge and the entrepreneurial experimentation, it is important to build technological hubs that host comprehensive cultivation and processing facilities that are accessible and user-friendly. By user-friendly it is meant that the facilities are relevant, and that they are modular and scalable. By accessible it is meant that the facilities are built and managed so that various actors, for example RTDs, enterprises and entrepreneurs, can use these facilities for testing and evaluating their technologies at commercially relevant scales and also for developing complementary new technologies and business plans. The size of these facilities should be determined by the size and the type of the market the primary macroalgae product is to enter. Thereby if an active macroalgae ingredient is the primary product, a commercial-scale facility for cultivation and processing of macroalgae can be 100-1,000 times smaller than an equivalent targeting biofuel production. The scope of the technology hubs should be centered on medium and high added-value macroalgae products, e.g. for the food market.

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[13] Integrated Multi-Trophic Aquaculture

♦Develop technology hubs and centres of excellence for macroalgae

Ideally these technological hubs will shape into centres of excellence, which in addition to facilities, will offer knowledge and expertise to developers and entrepreneurs, in areas such as policy and legislation. This is particularly important because the first users of the cultivation technologies will likely be entrepreneurs active in the aquaculture industry, and the aquaculture sector is fragmented (dominant players are SMEs). The development of user-friendly and accessible facilities at scales relevant for the industry will allow not only entrepreneurial experimentation and knowledge development, but also more reliable estimation and better understanding of the benefits and costs of the technologies in a range of market situations.

Recommendation 3: Develop tools to create sustainable macroalgae value chains

♦Support networks focusing on macroalgae

Given the current phase of development there is a strategic gap to be filled for an official macroalgae network that will support, among others, IMTA developers and entrepreneurs access pooled scientific and learning-by-doing knowledge as well as other resources across the innovation and value chain. Only few complete value chains were identified; mostly in France, while Ireland is more active in product development from harvested macroalgae. There is no national or EU macroalgae network other than the national and EU R&D macroalgae projects that, by definition, are time restricted. Associations like EABA[14] and ISA[15] organise networking activities for macroalgae producers and end-users. However they have no allocated country contact points that could form local working groups and disseminate and hold national or even regional networking events.

The networks, as well as matchmaking and knowledge exchange activities, should focus on 1) probing the interests of existing businesses to integrate new macroalgae technologies into their business models, 2) engaging with large enterprises, 3) develop open innovation events where companies with unused patents could share them to benefit from win/win collaborations, 4) showcasing benefits and success stories from projects incorporating macroalgae biorefining, co-product development and industrial symbiosis. Networking actors across the innovation and value chain, both nationally and international, is crucial for developing complete value chains and exchanging knowledge. This will also induce development of new knowledge in a synergistic fashion, e.g. connecting actors from macroalgae cultivation, IMTA, macroalgae processing and product development (including biofuel production and blending), thereby such a network will support marketability of macroalgae.

♦Map marine and coastal areas available for macroalgae developments

The development and launching of an on-line map holding information on: 1) the available and suitable areas for macroalgae cultivation, and 2) existing coastal and pelagic industrial activities with infrastructures suitable for hosting and integrating macroalgae cultivation technologies, is a fundamental prerequisite for the sustainable development of the sector. Macroalgae's value proposition as an essential ingredient of blue growth and marine development can play a vital role in the further development of the sector. However, currently macroalgae marine aquaculture in NW Europe competes with other industries for marine space, e.g. fish and mollusc aquaculture, tourism etc., and little is known about the availability of marine and coastal areas that could host new developments without disturbing existing markets. Currently, administrative procedures for production of new aquaculture licenses are so

[14] European Algae Biomass Association
[15] International Seaweed Association

complex, lengthy and handled-by-case, that it is virtually impossible to secure the necessary permissions. Creating an official map would enable more integrated marine and coastal spatial planning, and also accelerate administrative procedures for new licenses and thus increase sustainable business creation.

A national (potentially EU-wide) holistic assessment of coastal and pelagic three dimensional space available and suitable for macroalgae cultivation would unlock the potential of creating new businesses, integrating technologies and building sustainable industrial symbiosis concepts in existing industrial activities, like e.g. IMTA, wind farms, oil & gas platforms. On this basis, the map should also include data from existing coastal and pelagic facilities associated with marine activities, such as aquaculture and renewable energy, e.g. wind farms, wave energy installations, docks and platforms, etc.

Map existing infrastructure that could form macroalgae clusters

In addition to the suggested online map above, a supplementary online map should be developed containing data on existing industrial processing and logistics infrastructure neighbouring the coast. The map will support the identification of opportunities for future business and partnership developments and thus development of macroalgae value chains, by connecting macroalgae cultivation facilities with available inland processing industries and existing infrastructure from other marine developments.

Recommendation 4: Increase transparency of societal and market benefits and costs of macroalgae

While the industry has made considerable steps in the development of macroalgae nurseries and long-line pilot facilities, and integrated the latter in innovative IMTA concepts and other industrial symbiosis projects, it is still considered as being at the nascent stage. There is no clear view of the main societal and market benefits and costs associated with macroalgae cultivation technologies and macroalgae (energy) products. The identified macroalgae businesses in Ireland and France focused mainly on food and feed markets, personal care or soil products, while the environmental services of macroalgae cultivation have yet to be fully considered. By contrast publicly funded research around algal energy is very active.

♦ Build tools to benchmark economic and societal benefits and costs of macroalgae cultivation

To be able to optimise macroalgae cultivation and assess environmental and economic performance, a series of systematic methodologies assessing the associated benefits and life-cycle costs are essential. Cost benefit analysis is of strategic importance for production of added value products and fuels, but also for provision of bioremediation services to organic fish aquaculture or nutrient-rich marine environments. Therefore, techno-economic and LCA models will play an intrinsic part in developing a sustainable bioeconomy. Due to the scale and synergistic nature of the applications with the marine environment the development of such tools is expected to be a very complex task and it will require consultation by many stakeholders. A first effort was undertaken in EnAlgae project with the development of the Decision Support Toolset (DSTs); however building upon and expanding these tools is of strategic importance. Dissemination strategies and activities should continue once the tools are released and development projects terminated so knowledge does not slowly fade out and get lost (see also recommendation 1.3).
If in addition to the tools, the results are translated in a manner that allows the comparison of findings and the benchmarking of systems; this will help with aligning the expectations and visions surrounding macroalgae cultivation. Identification of benefits and costs will help in firmly positioning cultivation technologies in the aquaculture sector. These tools should preferably be used on large scale projects

because experience has shown that environmental and economic performance is greatly affected by project scale. This is another reason why the nascent industry has a need for accessible demo-scale facilities for testing and building business cases (see recommendation 2.1).

♦ Ensure effectiveness of macroalgae advocacy coalitions

Effective advocacy activities of the existing macroalgae trade associations will play an intrinsic role in the increased awareness of macroalgae cultivation and products. Successful and sustainable business models should be better showcased and presented to the local communities, entrepreneurs, relevant organizations etc. This will also require an increase in the associated entrepreneurship experimentation, market development, and strategic policy development. A national advocacy organization featuring networking services at regional, national and EU level (as described in recommendation 3.1), would be very beneficial.

Facilitate unrestricted and unobstructed dissemination of research and innovation findings

Routes for dissemination of the outputs from publically-funded research and innovation projects need to be considered to encourage authors to publish results in open access scientific articles, to allocate a budget for publication costs, whilst also supporting digitisation of world academic libraries making them accessible to all users. Finally, macroalgae networks and associations should also be in a good position to develop networking activities for knowledge exchange and open access innovation. This is very important for maximising the impact of disseminated research, in the form of innovation development and deployment, and transparency of research and funding.

Recommendation 5: Produce, maintain and supply technical and business competencies supporting macroalgae cultivation and biorefining

In recommendation 2, it was suggested building centres of excellence for macroalgae technologies. In addition to the benefits listed previously, the development of a technological hub or centre of excellence will have dual impact on macroalgae expertise and competencies: 1) it will help attract and geographically accumulate workforce and students holding competencies and expertise around macroalgae cultivation, plant biology, marine ecology, aquaculture symbiosis, and macroalgae processing, and 2) it will help prevent dilution or loss of competencies, something that happens for example in academia when macroalgae R&D projects are not renewed.

Support bio-entrepreneurship education

Because business ventures working with macroalgae cultivation and processing are underpinned by complex and quickly-developing bioscience and bioengineering e.g. biorefineries and industrial symbiosis, but also surf across fast-moving markets and changing policies and regulations, a new specialised field has emerged best meeting these new demands, called bio-entrepreneurship. Many pioneer countries in the fields of bioengineering and biotechnology have introduced such educational programs. Setting up bio-entrepreneurship programs and courses 1) helps new entrepreneurs understand knowledge-based business, bio-innovation and bioeconomy better, and 2) develop bio-entrepreneurial skills for process developers and engineers. Both objectives will facilitate bridging the language and trust gap between entrepreneurs and developers and it will result in boosting macroalgae business development, new technology integration, and business sustainability.

Secure an even flow and supply of technically-skilled macroalgae workforce

Apprenticeship or internship programs help workforces develop competencies and expertise in industrial environments; something that for the nascent macroalgae industry is very precious. Apprenticeships will have to evolve in line with the needs of the market, starting at small scale, as currently the market is in a nascent stage.

Although universities in France and Ireland were found to have accumulated expertise and competencies from R&I activities around marine aquaculture and biomass processing, these are typically constrained by application scale. Lab processing equipment that is used in education (university etc.) is limited by size from bench and lab to pilot scale in best case scenarios. On the other hand, the industry has an increasing need for technical expertise for larger scale projects, which is not available from universities or current RTDs. This is especially important for technical qualifications, but it is also of increasing importance in business management. At the same time there is already an identified gap between what skills new workforces possess and what the industry needs for expanding activities, integrating new macroalgae technologies (e.g. IMTA), and improving sustainability of business, which needs to be covered in time.

Recommendation 6: Introduce a strong and reliable framework supporting macroalgae commercialisation

Some national policies, e.g. in Ireland and France, supported macroalgae development for production of a variety of market products like food and bioproducts, which will play a major role in the shaping of the NW European biobased economy and sustainable marine development. Despite this, the majority of national and EU policies did not clarify the status and role of macroalgae e.g. energy policies, and some regional policies and laws for spatial planning and industrial permitting were criticised by the EU Parliament as being an impediment to development of the sector, such as in the case of France[16]. Finally although many product regulations were formed in the EU regime and then implemented at national level, some national regulations for food and feed products were found stricter than those imposed by the EU regulations, which could again be an impediment as well given the heavy bureaucratic system of some countries, e.g. France.

♦ Develop a strong aquaculture EU policy that supports marine macroalgae production activities

A dedicated EU aquaculture policy (e.g. Common Aquaculture Policy), aimed at developing a marine macroalgae industry, could be a way forward, providing greater support for emerging macroalgal industries and their IMTA synergies with other aquaculture sectors. This new policy should be aligned with existing EU coastal and marine policies, and in particular with the Water Framework Directive (WFD), the Marine Strategy Framework Directive (MSFD) and the Integrated Coastal Zone Management (ICZM). Although a coherent marine/oceans EU policy is still under development, the opportunities presented for 'blue growth' by marine macroalgae production and IMTA more generally are highly significant, thereby warranting further discussion in EU policy circles. Development of a strong aquaculture policy will define a clearer direction and establish macroalgae cultivation as a strategic industrial activity; it will initiate and reinforce development support actions including economic support of R&I and deployment activities, and finally it will set priorities and goals connecting blue growth with

[16] http://www.europarl.europa.eu/thinktank/en/document.html?reference=IPOL-PECH_ET%282009%29431568

sustainable aquaculture[17] and macroalgae cultivation that effectively will spread top down to national and regional policies regulations and laws.

♦Include macroalgae in circular economy policies

A recommendation related to the developing circular economy framework is incentivising strategies for recycling industrial side-streams containing soluble nutrients, like nitrogen and phosphorus from neighbouring or co-located industrial activities, e.g. fish and mollusc aquaculture, agriculture (run-off irrigation water) etc., to “fertilise” macroalgae production. Such material exchange processing lines are cornerstones in industrial symbiosis and organic aquaculture. Linking industries for material and energy exchange, e.g. industrial symbiosis and biorefineries, could be better incentivised by e.g. making such projects a priority in EC R&D programmes, and also by creating economic incentives for such projects in industrial zones (regional government).

Regional governments could incentivise development of industrial symbiosis projects by acting as a catalyst for development of business plans, by attracting funding and competencies in the area, by creating events etc.

♦Define LCA methodology and carbon accounting of macroalgae biorefining

Expanding recommendation **Error! Reference source not found.**, clarification is required for carbon accounting systems used for algal renewable fuels. Macroalgae are photosynthetic marine plants that do not require agricultural land, and convert CO_2 into biomass feedstocks. When products falling in different categories are produced from macroalgae, e.g. food, added-value products, transport fuels, heat, it is not clear a) how primary and secondary products are defined, b) what LCA methodologies should best be applied and c) how carbon emissions from cultivation and processing are allocated to algal products. Clarification of the LCA aspects for macroalgae cultivation and biorefining can influence market and technology development as the large amount of energy required for macroalgae cultivation can potentially impact the sustainability credentials of the fuels and products produced.

♦Establish stable strong advanced renewable fuel policies that support macroalgae

Establishment of stable trajectory targets, support measures and mechanisms for renewable fuel is an important factor for the deployment of algal energy technologies. The rapid alteration of the national and EU regulations for renewable fuels create long-term uncertainty for investors and can undermine entrepreneurial experimentation.

It is not entirely clear how biofuels derived from macroalgae would be treated under the EU RED. The recent amendment of the EU RED[18] 1) placed a cap of 7% for crop biofuels contributing towards the target for transport and 2) included an extended list of fuels and feedstocks under Annex IX that will contribute towards a separate “advanced” biofuel sub-target, which includes macroalgae but only if “cultivated in ponds or photobioreactors”. Marine macroalgae could be considered as an advanced feedstock (Annex IX) provided it complies with the cultivation conditions mentioned (which is not the case for the scoped technology) or if “cellulosic material” residues from a biorefinery are processed into transport biofuels (e.g. bioethanol). However, there remains a risk that macroalgae cultivated for sugars or starch could be included within the crop cap and would not be considered within the advanced biofuel

[17] http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1446571120040&uri=CELEX:32009R0710
[18] https://ec.europa.eu/energy/en/topics/renewable-energy/renewable-energy-directive

subset. In light of this lack of clarity, clearer indications are required that macroalgal biofuels will be considered as advanced fuels and would exempt from a cap on crop-based fuels in order to accelerate macroalgae biorefinery entrepreneurial experimentation/production and mobilise innovation funding.

The advanced fuel sub-target under the RED is set at just 0.5% of final energy consumption in road and rail transport, far lower than levels originally suggested by the Commission and Parliament. The target is only voluntary, with member states able to set a lower target if so desired, and is also only set to 2020. Beyond 2020 and to 2030 the "policy framework for climate and energy" outlines a new set of ambitious targets for renewable energy and GHG emissions; however beyond 2020 the framework introduces targets that are binding only at EU level, and not at country level, and also removes targets for individual sectors, e.g. transport targets. It is more likely that mandated, ambitious targets for transport and long-term trajectories will be required to provide the necessary certainty for investment in advanced biofuels given the recent policy and market instability faced by first-generation biofuel investors.

♦ Streamline regulations for non-energy macroalgae products

The EU and national governments should better align the position of algal-derived food and feedstuffs in their regulatory regimes. There may also be a need for greater cooperation with international standard setting organisations to develop global benchmarks for such end-products. Also, regulatory barriers e.g. on the trace elements limits (e.g. Arsenic, Iodine), need better harmonisation across product end-uses (e.g. food and feed) and in describing chemical speciation (organic, inorganic, total). By streamlining macroalgae product regulations, the market will effectively shape around these specifications, with more investors being attracted to fund a new market business.

Establish multi-species aquaculture licences and an EU level aquaculture license scheme

Development of a European aquaculture license would accelerate procedures and overcome regional and departmental administrative discrepancies met in countries such as in Ireland and France. The current administrative and bureaucratic system raises a major barrier to potential new business development of macroalgae cultivation, due to the complex and lengthy procedures followed to issue a new license. As a result it is of critical importance to accelerate the licensing procedures. However, because of the nature and the combined use of marine environment, it is important that the licensing process should be in full consultation with relevant stakeholders.

Particularly in regard to IMTA, major regulatory obstacles were found. In Ireland, for example, the current marine spatial planning licencing system could issue only single-species aquaculture licences, and not multi-species licences. Moreover, the current system used an unofficial zoning system for aquaculture, where in every zone only one species was allowed to be cultivated. For IMTA to be taken up by the aquaculture industry there would be a need for updating old practices of marine aquaculture zoning in NW Europe and introduction of regulations that allow issuing of multi-species licences.

♦ Enlist macroalgae production activities in the EU IED Directive

Under the Industrial Emissions Directive - IED[19] (previously Integrated Pollution Prevention Control Directive, IPPC) and other EU environmental protection measures, large-scale marine macroalgal production facilities (and IMTA concepts) would be subject to high levels of industrial permitting. However, such industries are not specifically listed in the IED legislation or guidance issued to national

[19] http://ec.europa.eu/environment/industry/stationary/ied/legislation.htm

governments. One recommendation could be that the IED Directive and its implementing requirements is amended to support such industries and thereby provide greater clarity for producers and regulators, streamline procedures and also ensure a harmonised approach to permitting across Europe.

Moreover, in some NW European countries' regulations, e.g. in France, there was regional and departmental authority discretion in spatial planning and decision making. However, national governments could instead provide more planning incentives for macroalgae production, through supporting macroalgae cultivation in strategic developmental objectives, for example in spatial planning, and in energy and industrial policies.

Investing in Opportunities

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EnAlgae is a four-year Strategic Initiative of the INTERREG IVB North West Europe programme. It brings together 19 partners and 14 observers across 7 EU Member States with the aim of developing sustainable technologies for algal biomass production.

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