# EnAlgae in conclusion: Products and impacts

2015

# contents


Foreword........................................................................... 3

Introduction....................................................................... 4

EnAlgae bridge.................................................................... 6

EnAlgae in context.............................................................. 13

EnAlgae legitimation........................................................... 20

EnAlgae legacy.................................................................... 25



Produced by researchers working within the EnAlgae consortium

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# foreword

This 2015 EnAlgae Report Card summarises outputs from our project exploring the potential for algal biomass to deliver (literally!) green, sustainable energy and resources. So what have we achieved?

Well, one of the major ideas enthusiastically considered 5 years ago was the potential role of algae in energy generation. With the barrel cost of oil almost halving, and revised estimates for the realistic potential for algal biofuels coming from the EnAlgae project, it now looks highly unlikely that algae can contribute significantly to Europe's need for sustainable energy.

This could be taken in a negative light, but I have always considered "energetic" algae to refer not so much to energy but to their great potential for commercial exploitation. And many technologies required for algal biofuels are required for the reliable mass production of algae for other sectors - food, nutraceuticals, etc.

The need for food, alone, is just as important to Europe as is energy, and algae contain valuable dietary components for humans. Rather than plunder dwindling oceanic fish stocks for these components, we can obtain them from algae, while potentially simultaneously using the algae to remove excess nutrients from waste waters.

Major legacy products of EnAlgae will do much to further the continued expansion of European algal industries. These products include manuals of best practice and standard operating procedures, a decision support tool that enables a ready-reckoning of plausible levels of production and hence of commercial viability, and a network for future collaboration. These outputs are products to be proud of, evidence that the hopes and € invested in the project have been well spent.

I hope the contents of this report card will serve as a useful reminder of what we have achieved, and promote future energetic research to exploit algae to European advantage.

Yours sincerely,


Prof. Kevin Flynn, EnAlgae Project Director

Algal Research

College of Science, Swansea University

Swansea SA2 8PP, UK

EnAlgae brought together 19 partners and 14 observers across seven EU Member States. It aimed to reduce $CO_2$ emissions and dependency on unsustainable energy sources in North West (NW) Europe.

# EnAlgae project

The EnAlgae project developed sustainable technologies for micro and macroalgae biomass production and assessed the potential for, and barriers to, their further development and comemercialisation.

The project assessed the potential for producing energy and fuels from both microalgae and macroalgae in NW Europe, in accordance with **three specific objectives:**

1. to develop a network of pilots and demonstration sites and identify strategic factors for optimising the algae cultivation environment;

2. to undertake a technical and economic feasibility analysis to determine if algae use can be of added value to NW Europe;

3. to perform a system analysis to identify the political, economic, social and technological opportunities and barriers for producing energy from algae.



# report card's user guide

The 2015 report card is presenting the main findings and achievements from the last four years of collaborative research.

It is also setting out the products of EnAlgae that are passing on to the project's partners EUBIA and AIN, who will host and maintain them beyond the completion of the project.

Finally, the card is presenting a list of policy recommendations that will effectively support the further development and commercialisation of the algal industry.

The card is divided in **four sections:**

- **EnAlgae network/bridge** shows the results of the collaborative work from the nine pilots. This includes a unique portfolio of Standard Operating Procedures (SOPs) and Best Practices (BPs), which will be a valuable tool for macro- and micro-algae producers. (See pages 6-12).
- **EnAlgae in context** presents the resource mobilisation and market development of algae production and product development – including algal energy products. This section also looks at the economic and environmental performance of algal biofuels using data from the nine pilots. It concludes with a list of policy recommendations to develop and commercialise the algal industry. (See pages 13-19).
- **EnAlgae legitimation** shows the many national, regional and local dissemination activities engaging the whole community in NW Europe. (See pages 20-21).
- **EnAlgae legacy** sets out the main products of EnAlgae: the Decision Support Tools (DSTs) and the Algae International Network (AIN). Each DST product is explained and illustrated, and we also sum up the aims of the AIN – which was recently launched by EUBIA and EnAlgae. (See pages 22-27).

## the voice of the EnAlgae pilot leaders on the value of the EnAlgae network:

**Q1: How has the EnAlgae pilot network induced the development of technologies, processes, markets or competences?**

**Q2: What lessons you have learned from the EnAlgae pilot network, and how has this network empowered the entire algae community in NW Europe?**

### InCrops, Cambridge, the UK:

*A1: "Our EnAlgae research has led to new collaborations and research avenues, such as those with the British Antarctic Survey, which enabled me to study terrestrial algae in Antarctica."*

*A2: "The success of the EnAlgae project has meant that the University of Cambridge has invested in a new dedicated Algal Innovation Centre to advance algal biotechnology research"*

Dr. Matt Davey

### Ghent, University, Kortrijk, Belgium:

*A1: "Collaborating with local companies is key to boosting the algal economy. EnAlgae outsourced Bebouwen & Bewaren and CATAEL, two innovative Belgian SMEs, for constructing our pilot-scale algae facility."*

*A2: "The catching enthusiasm of EnAlgae seaweed partners empowered bridging the Belgian seaweed cultivation gap, especially for integrated multitrophic aquaculture systems."*

Dr. Sofie van der Hende

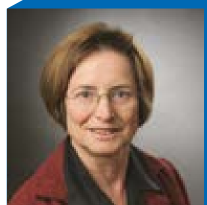
### Swansea University, Swansea, UK:

*A1: "Swansea University was able to develop technological innovations for algal cultivation using nutrient-rich wastewater and $CO_2$ from local industries."*

*A2: "The Swansea University pilot has provided opportunities to demonstrate scientific advancements to companies and will continue to facilitate algal R&D into the future."*

Dr. Alla Silkina

### htw saar, Saalrandes, Germany:



*A1: " The open and trustful sharing of experience among EnAlgae pilot operators encouraged us to pursue the integration of a microalgae production line in a land-based production of marine fish."*

*A2: "The interaction with the EnAlgae network helped us solving technical challenges e.g. caused by the seasonal light and temperature changes."*

Dr. Anneliese Ernst

### Plymouth Marine Laboratory/ Boots PLC, UK:

*A1: "EnAlgae funding has enabled us to demonstrate that a robust algal strain can be maintained continuously for periods > 6 months in a large scale photobioreactor coupled to the $CO_2$ emissions of a power plant."*

*A2: "The opportunity to showcase PML's microalgal biorefinery to the EnAlgae community at the Open Day provided an ideal opportunity to network and exchange ideas."*

Mr. Steve Skill

### ACRRES, Lelystad, Netherlands:

*A1: "The energy use of algae production is key to decrease the cost price and this is important to enlarge markets. EnAlgae allowed us to invest in an energy efficient harvester that can decrease harvest energy need by 70-80%."*

*A2: "Within the network we exchanged best practice information. This allowed us to improve our monitoring and management."*

Ir. Chris de Visser

### Queen's University Marine Laboratory, the UK:

*A1: "Through the EnAlgae pilot upgrade, QUB obtained InvestNI funding to develop a commercial prototype system for juvenile kelp transport across the NWE region."*

*A2: "The EnAlgae network has highlighted the importance of stakeholder engagement in cultivation system development and how this varies across the countries, giving us ideas to try in Northern Ireland (NI)."*

Dr. Karen Mooney

### National University of Ireland, Galway, Ireland:

*A1: "The network of EnAlgae seaweed pilots has demonstrated that productivity has increased hand in hand with the development of farm operator competencies."*

*A2: "We learned that we should scale the seaweed pilot facilities just right; small enough to be a useful demonstration, and large enough to provide realistic values of biomass productivity. "*

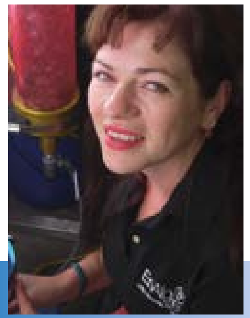
Dr. Maeve Edwards

### CEVA, Pleubian, France:

*A1: "The EnAlgae project allowed us to invest in a raft culture system 3 times more efficient for seaweed farmers, than the traditional longlines systems."*

*A2: "Through transparent and regular exchange on best practices, or technology development, the European seaweed connection is born!"*

Jennifer Champenois



Dr. Alla Silkina
Swansea University, UK

## develop and exchange
# SOPs for mass production of microalgae

EnAlgae focused also on the documentation of standard operation procedures (SOPs) for data collection characterizing microalgal biomass production.

SOPs from six microalgal pilot plants facilities have been collated in a single document, to establish uniform procedures for the acquisition and management of data collection. Sections cover data collection (continuous, as applicable) on the following types of parameters:

- growth parameters during algal culture,
- composition of harvested biomass, and
- nutrients and environmental parameters.

SOPs produced through this collaboration are listed in the table.

Included are considerations of accuracy and precision, with an aim to standardise methods between different analysts and institutions. The generation of such data series is an essential prerequisite for the parameterisation and validation of mathematical models of algal biomass production for commercial exploitation.

The six microalgae pilots plants focus on algal biomass production and/ or waste remediation. Data gathering for producing the SOP document reflected the particularities of both product lines.

Public access to this document will help algae stakeholders in North West Europe identify methods to optimise their algal cultivation strategy and provide appropriate assessment of system performance. It will thus aid system operation and indicate potential bottlenecks; this is particularly so if married to model-based decision support tools.

| Environmental parameters |
|---|
| Temperature |
| pH |
| Salinity |
| Light (PFD/PAR) |
| **Dissolved analytes** |
| Ammonia & Ammonium ($NH_3$, $NH_4^+$) |
| Nitrate ($NO_3^-$) |
| Nitrite ($NO_2^-$) |
| Total dissolved N |
| Soluble Reactive Phosphate (SRP; $PO_4^{3-}$) |
| Total dissolved P |
| Silicon (Si) |
| Total dissolved inorganic and organic Carbon |
| Dissolved Oxygen |
| Biological Oxygen Debt (BOD) |
| Chemical Oxygen Debt (COD) |
| Iron (Fe) |
| **Growth Parameters in Microalgal Culture** |
| Biomass Weight (AFDW/DW/VSS/TSS) |
| Absorbance (optical density, OD) |
| Cell count and biovolume |
| Chlorophyll & photosynthetic efficiency |
| **Cellular composition** |
| Proteins |
| Carbohydrates |
| Lipids |
| Chlorophyll a |
| Carotenoids |
| Elemental content (C,N,P) |
| Fatty Acids (FAME) |
| Heavy metals (B,Cu,Fe,Mn,Zn,Al,Ca,K, Mg) |
| **Biogas outputs** |
| Biochemical methane potential |
| Biogas analyses ($CH_4$, $CO_2$) |
| Biogas collection |



EnAlgae bridge

## develop and exchange
# SOPs for mass production of macroalgae

Dr. Karen Mooney
Queen's University Marine Laboratory, UK

All three macroalgae pilot sites have developed a data template for algal biomass and biochemical data and environmental data for kelp ongrowing systems. QUB hosted a workshop bringing together pilot operators and key partners from other work packages to ensure the template was clear and understandable to a range of backgrounds, had sufficient data for biological analysis and modelling and was future-proof for several years' worth of data. We have also drawn up a booklet of Standard Operating Procedures (SOPs) for every method used: from spore release to deployment to biogas production and analysis.

In QUB we have learned that although the hatchery methods for zoospore release and gametophyte development remain relatively consistent, this is less so for ongrowing methods. Due to variations in geography, access to resources and time available, there can be a large variation in kelp cultivation methods. Simple longline designs tend to be the best, with significant progress being made in CEVA on incorporating this into a flexible raft design which can increase longline density.

It is important to identify those techniques best suited to the resources available and if one method doesn't work well, there is usually another that will be better. Also, having a long term database will greatly help to identify key factors in cultivation for both kelp growth and biochemical composition. Standard methods for testing and analysis will aid in identifying key algal strains across a range of intended applications.

develop and exchange

# Best Practice for algal strain maintenance

**Prof. John Day**
Scottish Association for Marine Sciences, UK

Sustainability of biotechnological processes crucially depends on the functional stability of the biological resources on which they are based. Algae are assumed to be stable on prolonged culture, but this is not always the case as highlighted in our recent EnAlgae output (1). Therefore, we have focussed on improving the security of key strains through optimising conventional culturing protocols and the application of cryopreservation (ultra-low temperature storage).

An initial survey revealed that whilst some partners follow appropriate standards, there was limited relevant knowledge in some organisations to ensure stability and sustainability of their algae. A report exploring the issues associated with algal maintenance was drafted, which has led to the development of Best-Practice Standard Operating Procedures (SOPs), available to the wider algal biotechnology community.

Ultimately the functional and genotypic stability of algal can only be guaranteed by cryopreservation. A hands-on training workshop was held at SAMS, which allowed exchange of current best practice and the development of SOPs for wider use.

Using archive material and experimentation an evidence-base with respect to the stability and longevity of cryopreserved algal sample has been developed. This has facilitated the formulation of best practice with respect to storage, stock control and management of refrigeration failure.

Finally, a paradigm shift that has occurred during the EnAlgae project has been the biotechnological use of algal-bacterial consortia. Working with collaborators in Cambridge and Swansea Universities we have developed innovative cryopreservation protocols to ensure uninterrupted availability and functionality of exploitable microalgal-bacterial consortia.

(1) doi: 10.1515/micbi-2015-0001



EnAlgae bridge

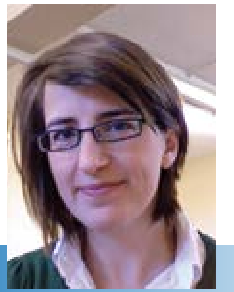
develop and exchange

# Best Practice for mass production of microalgae and MAB cultures

**Dr. Daniel White**
Plymouth Marine Laboratory, UK

Our goal was to produce informative and comprehensive Best Practice guidelines on cultivation of microalgae and Microalgal bacterial flocs (MAB) for biomass production and utilisation focused on North West Europe. We have produced two key outputs. The first is a short, informative Best Practice video where the microalgae pilot facility managers were given the opportunity to respond to Best Practice questions covering topics such as the types of pilot operation developed, control parameters monitored during production, and approaches to harvesting microalgae biomass. The video was designed to act as an introduction and taster for the larger and more comprehensive second output, a Best Practice Report, on microalgae cultivation at pilot operation scale. This report includes detailed descriptions of EnAlgae pilot operations including raceway and different photobioreactor systems situated across Europe; the use of different waste streams to replace chemical nutrient sources for algal cultivation; technologies for a low energy biorefinery platform for a photosynthetic carbon capture system, and fully automated integrated microalgae production in a recirculation aquaculture system. Best Practice information is presented on the preparation, controlled production (including waste-stream remediation), harvesting and valorisation of microalgae biomass.

This process of Best Practice formulation and documentation has enabled the technology developers to highlight their refined operation processes that they have developed as a result of their extensive research and development carried out within the EnAlgae program. We envisage that the Best Practice outputs will serve as a useful resource and guide to future microalgae production practitioners and other general and potential microalgae production stakeholders across NW Europe.



Dr. Maeve Edwards
NUIG, Ireland

## develop and exchange **best practice for mass production of macroalgae**

The EnAlgae seaweed partners have spent four years working together to investigate the best ways to cultivate seaweed for biomass and further downstream products. The length of time invested in this research and the transnational collaborative nature of the seaweed programme is unique to NW Europe and indeed remains a rare occurrence further afield.

Two significant outcomes of the EnAlgae macroalgal research are the Standard Operating Protocols (SOPs) and the Best Practice handbook for seaweed cultivation.

The macroalgal partners recognised early on that we needed to achieve standardised sampling and cultivation practices, as well as acknowledging the advantages and disadvantages of our particular production facilities. In contrast to microalgal culture where a single photobioreactor design will suit a multitude of land sites, seaweed cultivation often relies on sea sites with significantly different conditions. Therefore, our SOPs and Best Practice documents are designed to reflect the various individual ways we achieved our production goals while incorporating inherent variation.

The documents start with best practice hatchery techniques for the species *Saccharina latissima* and *Alaria esculenta*. They include information on regional variation (e.g. seasonal availability of reproductive material which can vary by latitude). The documents continue with cultivation systems and methods at sea, as well as sampling and harvesting procedures. Crucially, the best practice handbook also refers to less successful methods or systems, as the EnAlgae macroalgal partners feel this will represent good value for money for the future European seaweed industry, reducing some of the risks of cultivation and therefore the associated costs in time and money.



## **state of the art of academic and industrial research on algae cultivation** in NW Europe

Kristin Sternberg
Agency for Renewable Resources (FNR), Germany

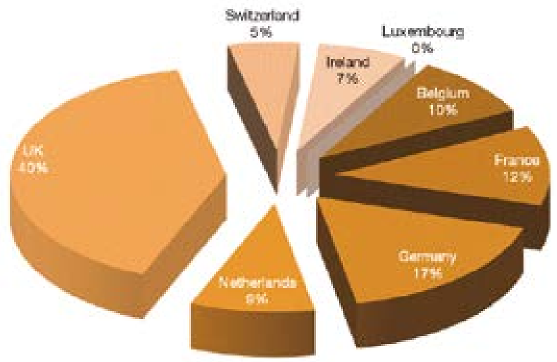
This action has produced:

- **An interactive database profiling academic and industrial stakeholders focusing on algae in NW-Europe, including their contact details, assets, market focus, and R&D projects**
- **Eight accompanying country reports summarising the findings of the survey**
- **A report providing an overview of national funding options for conducting algae related research in NW-Europe**
- **A factsheet summarizing results of a survey on the need for skills developed in the algae sector.**

The landscaping study resulted in identifying 283 institutions working with algae in North-West Europe, showing an almost equal distribution of scientific and commercial stakeholders.

The number of algae stakeholders identified varies significantly from none in Luxembourg and up to 77 stakeholders in the UK. See the distribution of algae stakeholders in North-West Europe in top-right graph.

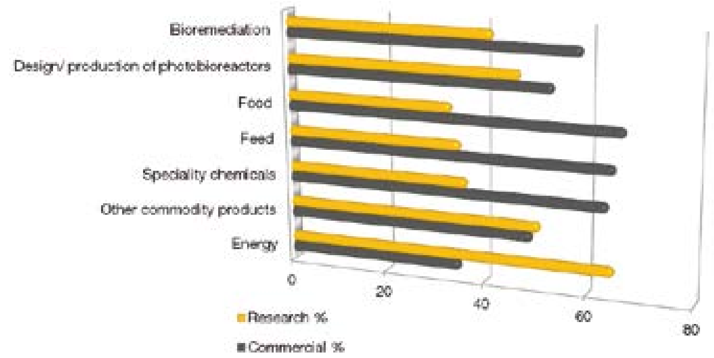
Regarding the targeted outlet for the algae biomass it can be summarized that industrial stakeholders concentrate on the material use of algae, i.e. for food, feed and specialty chemicals, whereas scientific stakeholders




focus more frequently on bioenergy aspects (see graph bottom right).

It can be stated that currently there are two different algae markets: one is driven by policy goals and the other driven by market economics. Public, algae related research funding almost exclusively concentrates on bioenergy aspects. A slightly new direction of the funding policies should be considered in order to achieve a better overlapping of these two approaches.

The assessments within this project action have shown that the use of algae solely for energy purposes is not economically viable in NWE. A more integrated approach with a cascading use of the valuable algae biomass (biorefinery concept) seems to be the most promising way, which should be supported in its further development.



# the political environment of algae production in NW Europe

Dr. Efthalia Arvaniti
NNFCC, UK

This task has produced:

- Landscaping of national strategies, policies and economic incentives schemes for 8 NW European countries on sustainable development and climate change, biobased economy, bioenergy, and environment and waste.
- An understanding of successful algae policies developed outside the NW European region.

Most national and regional policies landscaped reflect EU strategies and strategic targets. Nevertheless, all countries have set their own priorities and strategies in order to reach national targets. In many national strategies (e.g. Germany, Netherlands, Ireland,) algae are acknowledged as important biomass resources for the biobased economy. Among the landscaped policies, the most innovative ones were found in Ireland and in the Netherlands. Ireland is primarily scoping macro-algae, while Netherlands is developing both micro and macroalgae.

NW European countries' policies largely support bioenergy technologies like biomass power, biomass CHP, and AD, and they do this by creating support policies, providing financial incentives, and funding subsidies for R&D and innovation.

A factor that crucially influences decision making in bioenergy production is the Life Cycle Assessment (LCA) and the sustainability performance. This is an important criterion for government support for Switzerland, Germany, Netherlands, the UK, Belgium, and Luxembourg.

One sustainability criterion that has impact on energy crops, is the crop land footprint (e.g. Indirect Land Use Change, ILUC). Population-dense countries prioritise agricultural land use for food production and often do not support energy crop concepts. Unfortunately energetic algae were found to fall in this category, although algae cultivation in fact does not require agricultural land.

Is algae an energy crop or a waste resource? The answer to this has not been defined yet, as there were discrepancies and incoherence as to what role algae will play in the future. For example, in the UK, while some energy crop projects were financially supported by the UK Government, algae biomass was not eligible for support. On the other hand, in Ireland,fuels from macro-algae (seaweed) could receive double green certificates, due to their high sustainability performance index.





# the regulatory and licencing environment of algae production in NW Europe

Dr. Brenda Parker
InCrops, UK

The EnAlgae project has produced a report that outlines the regulatory and permitting frameworks of several NW European countries with regard to:

- Land and marine planning
- Environmental permitting
- Constraints on end use of products (both energy and non-energy products)
- Cultivation and processing of GM algae.

The current permitting, planning and product regulations across NW Europe do not significantly inhibit algal production, for both micro and macroalgal processes. The EnAlgae project facilities were able to secure planning permission or waivers with few problems encountered. Approaches to permitting did vary - despite an overarching EU regulatory context.

While EU policy is highly supportive of this nascent research, it is less obvious how European and national level policy will help future growth of the industry once processes are 'scaled up' towards full production.

At present, the current permitting and planning constraints applicable to large scale industrial facilities are not evident in the case studies for the EnAlgae pilots, because they are not fully representative.

Also the policy framework governing or supporting macroalgal production across Europe is poorly developed. Some limited national measures are evident in the UK, France and Ireland but EU marine and coastal policy, in the form of the Marine Strategy Framework Directive and Integrated Coastal Zone Management (ICZM) guidance, does not explicitly mention macroalgal production. A dedicated EU aquaculture policy within this broader policy agenda, aimed at developing a marine seaweed industry, may be one way forward.

Algal end-products are, to an extent, regulated by existing measures in European countries. Many products, such as chemicals and fuels, are subject to harmonised EU standards meaning, in theory, little variability in approaches is visible between countries.

However, the relative novelty of algal end-products means that they are largely regulated under existing measures that provide few direct incentives for the industry. For example, the main context for biofuels is set by Directive 2009/28/EC. However, this directive is primarily focused on first generation (crop based) biofuels and does not explicitly address advanced processes such as those based on algae. Sustainability criteria such as the RED requirement for significant reductions in $CO_2$ could limit algal production without some form of 'phase in' period.

For algal biomass produced by recycled material resources, e.g.'waste' bioremediation, according to existing regulations nothing that is labelled as 'waste' can be an input if algae are to enter the food / feed chain. For example in the UK, liquid digestate has to be PAS110 / ADQP compliant, and flue gas has to be part of HACCP assessment to identify and mitigate possible hazards and risks.

# LCA and Sustainability of algae production in NW Europe

Dr. Christine Rösch
Karlsruhe Institute of Technology (KIT), Germany

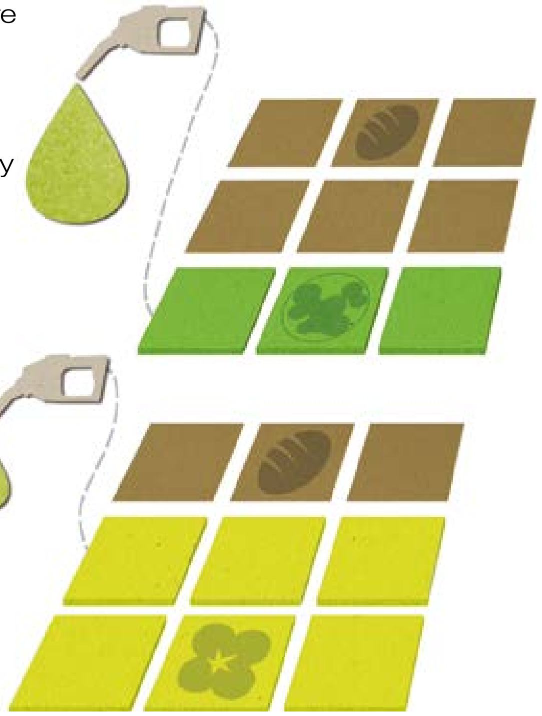
The environmental sustainability of the EnAlgae pilots has been examined using the life cycle assessment (LCA) method. The results were summarised in case study reports for the investigated pilots and provided in the DST. Most pilot data regarding biomass production and harvesting were collected directly on-site from the EnAlgae pilots, while the missing data was computed through mass and energy balancing or found in literature and databases.

The LCA case studies show that the resource footprint and the environmental impacts of energetic algae production are exceeding the ones of the fossil reference. This is generally applicable to both microalgae and seaweed production although seaweed production, showed better results compared to microalgae production systems.

For microalgae the unfavourable results are mainly related to the high electricity consumption for lighting and pumping during algae cultivation in the high-tech research facilities. However a significant potential exists to reduce the energy demand by adaptation of the processes and components for the purpose of energy production and by up-scaling of the system to better fit commercial requirements. For example the LCA of a microalgae raceway pond treating aquaculture wastewater in Belgium showed that up-scaling could reduce the carbon footprint of the system by 67% (1).

When compared to a typical agricultural energy crop like maize, the resource footprint of seaweed shows adverse results mainly due to fossil resources that are consumed during marine biomass production. However, more land resources are used for terrestrial biomass production, indicating that marine seaweed biomass meets the requirements to reduce pressure on land (2).

To produce a sustainable renewable energy carrier, it is crucial to optimise energetic algae production towards efficient energy use and to explore options for the co-generation of high value products and energy. Therefore, basic research in process and biological engineering is needed as well as large-scale demonstration projects to investigate economy of scale effects. Furthermore, algae biorefineries with energy as a co-product is a concept worth more investigation.



(1) doi:10.1016/j.biortech.2015.04.088

(2) doi:10.1016/j.algal.2015.06.018



EnAlgae in context

# macro and business economics of micro and macroalgae in NW Europe

Ir. Chris de Visser
Wageningen UR, Netherlands

This action produced:

- Three microalgae business economic models for open ponds, flat panel and tubular reactors, accompanied by a comprehensive report on the bio-economic micro-algae models
- One business economic model for macroalgae production, accompanied by a comprehensive report
- Business economic models for downstream processing to bioethanol, biodiesel and biomethane, accompanied by a comprehensive report
- A study on macro-economic potentials of algae products, and
- A survey describing algae initiatives across North West Europe.

The microalgae economic models have shown us that the cost price of algae is high while the extent to which scaling could decrease cost price is as yet unclear. In any case, energy use is high and sharp reductions are needed. The downstream models have showed us that commercial energy production based on algae is questionable, at least within the next 10 years. To develop further, the algae industry should focus on high value markets like food and feed additives instead. Effluent polishing could be an alternative market. While serving these markets, the industry will have to develop production and processing techniques that eventually allow the sector to serve more bulk markets like protein rich feed or food that at the same time could produce side streams for energy production. The macro-economic study has resulted in a comprehensive overview of market outlets for microalgae in both niche and bulk markets.

The macroalgae business economics have resulted in increased insight in the cost price built up of macroalgae. Cost price reductions should focus on capital cost for on sea installations and the combination of other on sea economic activities.

It is recommended that algae expectations for energy purposes are adjusted and that algae policies should be focussing on supporting the development of applications in high value markets on the short to medium term, and on alternative protein production for the medium to long term.

# policy recommendations for systemic barriers affecting algae production in NW Europe

Dr. Efthalia Arvaniti
NNFCC, UK

For four years several groups in EnAlgae collected data and information on factors influencing micro and macro algae production in NW Europe. These factors include academic and industrial research, LCA and sustainability, macro- and business economics, political landscape, regulatory and licencing framework. This work is presented in pages 13-17.

All the factors strongly impact on the development rate of algae cultivation technologies, and can slow down or even stop the further development. We studied how these factors influence the development of four promising algae cultivation concepts, 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 selected by the nine pilot technology developers. These were considered to be some of the most promising concepts for production of energetic algae in 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 the functions 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. At the other end of the scale, if a system function acted as a major development obstacle it was given a grade 1. The four case studies revealed that each studied country of NW European region supports and influences the development of algae cultivation innovations in a unique way. The spider web shows the seven system functions examined along with the allocated grades of three of the concepts studied.

Where a system function had a low grade, as shown in the spider-web, this was targeted for recommendations to improve performance, and thus accelerate development of studied algae cultivation concept. The text box below presents a preliminary list of recommendations for action to European policy-makers. The list 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.

**Rating of functionality of the innovation system supporting production technologies of microalgae in NL and in the UK and of macroalgae in FR: 1=forms a barrier, 5=forms a driver**


## A SHORT PRELIMINARY LIST OF POLICY RECOMMENDATIONS:

1) Increase competitiveness of algae 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 increase visibility of technical and business competencies supporting algae cultivation and biorefining

6) Introduce a strong and reliable framework supporting algae cultivation and algal products, including algae-from-waste.

# engaging with communities, businesses, and policy-makers of NW Europe

Since the project began in 2011, we've been keen to inform and include as many people as possible in our work and our vision. Over the past four years, we have embarked on a series of events and engagements which has brought us into contact with businesses, policy makers, school children, scientists, politicians and people with a general interest in sustainability.

We have attended conferences, held open days, visited schools and used social media as well as traditional outlets to link in with as many people as possible.

The figures speak for themselves:

- 358,925 people reached via activities focused on involving local communities
- 121,882 people reached through EnAlgae attending national level events
- 37,126 people reached at regional/local events

Left page:

1. Queen's Marine Laboratory Open Day as part of the Strangford Lough Maritime Festival, Portaferry, UK, 2014
2. Showcase for the Committee of the Regions ENVE Commission, Brussels, Belgium, 2013
3. Public engagement during Festival of Plants, Cambridge, UK 2015
4. Microalgae Biorefinery EnAlgae Open Day, Nottingham, UK, 2012
5. CEVA open day, Pleubian, France, 2015

Right page:

6. Algae food by local farmer at the EnAlgae Pilot Symposium in Kortrijk, Belgium, 2014
7. School visits to MaB-floc pilot at Alpro in Wevelgem, Belgium, 2014
8. Boat trip during CEVA EnAlgae workshop, Pleubian, France, 2014
9. Algae Event during EUBCE Hamburg, Germany, 2014

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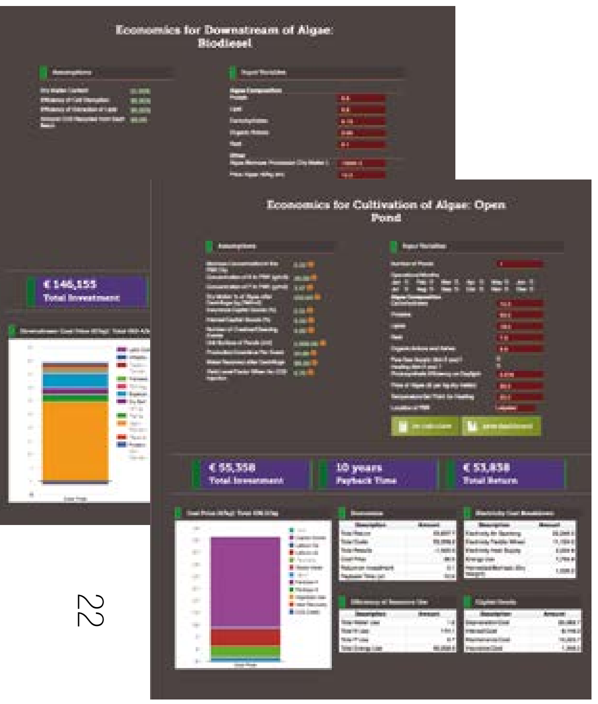
# Decision Support Tools designed for NW Europe

Dr. Lynsey Melville
Birmingham City University, UK

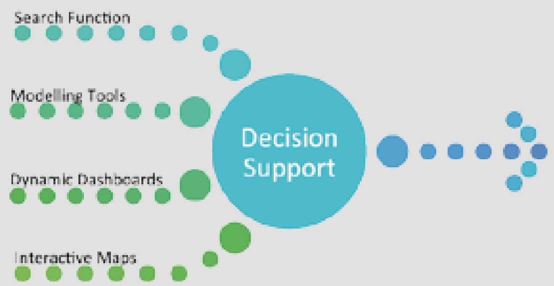
## ECONOMIC DASHBOARDS

The dashboard comprised a description of cultivation and processing systems, in the form of bio-economic models that combined an estimation of biomass production and resource consumption, with an economic assessment that provided a detailed cost price analysis. The dashboards have been developed for various cultivation methods including open pond system, flat panel system and tubular system, downstream processing including methane, biodiesel and ethanol wet-milling and seaweeds. End-users will be able to input their own data in order to evaluate the economics of various scenarios.




## DECISION SUPPORT

The Decision Support Tools (DSTs) was one of the key outputs from the EnAlgae project. This system, made up of several distinct and separate tools, has been carefully designed to support the promotion and adoption of algae based biotechnology projects in the NWE region. The design and functionality of the tools have evolved through close communication with both our experts who have specific process knowledge and with stakeholders who need a better understanding of the processes and opportunities arising from them.

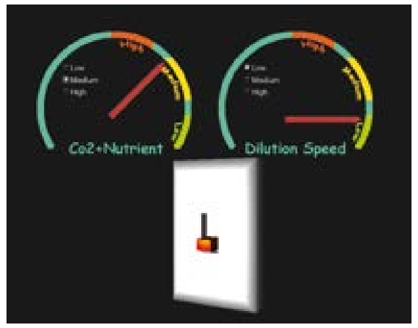



## STAKEHOLDER MAP

The stakeholder map presents the data collected from landscaping studies of academic and industrial research on algae cultivation and its use in general as well as for associated commercial activities. The map can be searched using a number of filters and features on the user controlled interface. For example location, contact names and other miscellaneous information on stakeholder activity can be displayed by using this tool. The map can be updated by adding new stakeholder data or modifying existing stakeholder information.


## 3D VISUALISATION TOOL FOR VIRTUAL ALGAE PLATFORM

The 3D visualisation tool has been developed to demonstrate the concept of algae cultivation and downstream processing. The end-users can interact with the cultivation system by adjusting parameters and visualising the impact on biomass productivity.

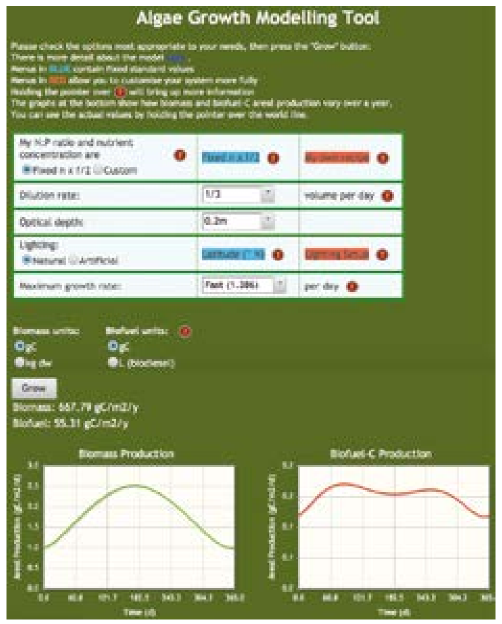



The whole process can be visualised by adjusting three parameters: $CO_2$ nutrients, dilution rate and light source. Dials are used to adjust parameters from low to medium and high. The light source can be adjusted by switching from natural to artificial.

The three parameters will impact upon the process by changing the flow of liquid and gas, productivity and therefore the biomass yield (and economics). Users can observe and interact with the platform in a number of ways by changing their view/ perspective or by manoeuvring around the system using an avatar.

## GROWTH MODELLING TOOL

The growth modelling tool was based on a well-founded mechanistic model of algal physiology and enables rapid calculation of biomass and biofuel feedstock production under a range of dynamic environmental conditions. The user interface provides scope for experimentation to investigate how the interplay between these various factors can guide strategy to attain optimal solutions. The end user has control over light availability (including artificial or natural), nutrient levels (in the form of dissolved nitrogen and phosphorus), harvesting rate and optical depth.



# Decision Support Tools
## designed for NW Europe

### GIS TOOL FOR LOCATING POTENTIAL ALGAE CULTIVATION SITES

This tool uses data from a geographic information system (GIS). This allows users to explore potential microalgae production sites based on proximity to resources and infrastructure. Data with high spatial resolution were used to identify resources such as waste nutrients and $CO_2$.

In addition, spatial data on waste nutrient sources that could be used for microalgae production is provided.

To give the users information on potential sites tailored to their needs, the results can be filtered using the following criteria:

- Areal biomass yield
- Site and reactor area
- Distance to road infrastructure
- Distance to nitrogen, phosphorous and $CO_2$ nutrient sources.

For further refining the results, the user can select different scenarios regarding the cultivation system (flat panel, tubular reactor, open pond), land use restrictions, and terrain restrictions that affect the outcome of the land availability and the yield calculations.

Statistics on national and several regional levels on potential microalgae areal yields and number of nutrient sources are provided as colour-coded maps to give the user an overview and to facilitate the identification of promising cultivation areas on a higher level.

To ensure consistency among the models used in the EnAlgae DSTs, the GIS tool was coupled to the techno-economic models used in the DST Dashboard for the calculation of the microalgae biomass yield and the demand for nutrients (nitrogen, $CO_2$ and phosphorous). This allows yield to be calculated for each potential site using site-specific data on mean temperature and global radiation levels.


# user guide to the Decision Support Tools

### HOW DO YOU USE DECISION SUPPORT TOOLS?

The Decision Support Tools were launched at the EnAlgae closing conference in Brussels at the end of September 2015.

The Decision Support System will be hosted on the EnAlgae project website and on the Algae Information Network (AIN) website. To find out more about the the tool, there will be contact details on the AIN website. For more information on the AIN, go to page 27.

The tools are accessible to everyone, however some features may require registration with a username and password. Such features include setting new inputs into the models that fit the user's study case, or downloading material to local computers.

Alongside the DSTs there will be further information in the form of a demonstration video. This will be a step by step guide on how to get the most from the tools.

### WHO WILL BENEFIT FROM DECISION SUPPORT?

These tools have been designed so that they are easily accessible to a range of stakeholders. We have worked closely with experts and non-experts to ensure that the user interfaces are clear, intuitive and interesting to all relevant end-user groups. The tools range in sophistication but can be used for educational purposes or to support decision making during project development and planning.


### FUTURE WORK (ADAPTABILITY)

The tools developed in the EnAlgae project were designed by experts in knowledge engineering. Algal biomass production is a relatively immature sector, and research is rapidly expanding. To ensure the information provided by the tools are relevant and up to date they have been designed in a modular and adaptive way which means as new knowledge and data emerges the tools can evolve.

For more information on these DSTs and future work please refer to page 26.

## EnAlgae legacy transition

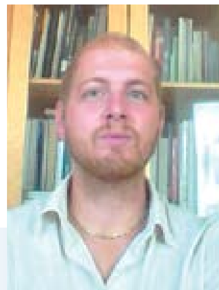
AIN
ALGAL INFORMATION NETWORK

We have developed the Algal Information Network (AIN) to support the algae sector in Europe beyond the life of the EnAlgae project.

The role of the AIN is to manage, improve and implement results obtained by the EnAlgae project and to organise an efficient training and information distribution strategy, addressed to key actors and stakeholders in each of the project regions.

**www.enalgae.eu**


## the Algae Information Network (AIN)



**Dr. Andrea Salimbeni**
European Biomass Association

**Hosted by the European Biomass Industry Association (EUBIA), the AIN offers the following services to members:**

• **Decision Support Tool.** The AIN website will host the EnAlgae Decision Support Tool, which will be able to help investors, authorities and stakeholders to analyse the competitiveness of algae business cases at regional and national levels.

• **Algae Sector Open Database.** The AIN will publish a detailed database based on most relevant EnAlgae market research and other European project results.

• **International and national projects dissemination.** A source of information from EC projects and public-private partnerships, providing a valuable overview on the current technology status, promising strategies, market potential and future perspectives.

• **Regional Algae Support Centres (ASCs).** Regional information desks, with designated experts, will operate as contact points to help stakeholders to tap into the algae market in each of the NW Europe regions.

• **Expert network and training:** Via EUBIA's office in Brussels and the ASCs, members will have access to European algae project dissemination events, technology training, and stakeholder workshops for businesses, research organisations, and policy and decision makers.

The above services will be coordinated through the AIN website, which will also be a source of industry-leading information on news and events, new policy measures and commercial initiatives, and project collaboration opportunities.

**www.algae-network.eu**

The AIN is open to all stakeholders who wish to benefit from the results and tools developed within EnAlgae and many other European Projects and initiatives. Membership is free.

>> EnAlgae and the AIN have already organized the highly successful 'Algae Event' conference series in 2013 and 2014.

>> Future events will include more specific workshops and technical training.

EnAlgae
collaborate innovate communicate

AIN
ALGAL INFORMATION NETWORK

To find out more information about the **EnAlgae** project contact the team at info@enalgae.eu.

To join the **EnAlgae** mailing list and receive project and industry updates please register at:

www.enalgae.eu

EnAlgae

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Investing in Opportunities

This project has received European Regional Development Funding through INTERREG IV B.

NWE

INTERREG IVB

*INTERREG IVB NWE is a financial instrument of the European Union's Cohesion Policy that funds projects which support transnational cooperation. The programme will invest €355 million from the European Regional Development Fund (ERDF) into the economic, environmental, social and territorial future of North West Europe.*