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Algae and aquatic biomass for a sustainable production of 2nd generation biofuels

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Executive Summary

The AquaFUELs project is the very first EU funded action on the field of algae biomass production for the creation of energy, in this specific case for the production of biofuels.

During the 18 months of work the partners put together their efforts and their scientific, legal, industrial and technical knowledge in order to understand the real potential of algae and other aquatic biomass as biofuels raw material.

The results of AquaFUELs paved the way to a better understanding of the overall economic feasibility of algae-to-biofuels production chains and to an initial assessment of their potential impact in terms of environmental, social and economic sustainability. Although the project findings confirmed that algae-based-biofuels are still at a research stage (the initial questionnaire identifies algae stakeholders as predominantly research institutes), a very promising infant industry is growing up in various EU countries. There is yet little consensus on the overall GHG and sustainability impact of algae, also since this kind of analysis has been conducted as extrapolation of research scale experiments. Macroalgae stand among the most interesting and promising potential raw material for second generation biofuels in the short to medium term (both in terms of feasibility and of sustainability), although important investment will be needed to test large scale productivities and scale economies. More research and industrial pilot tests will be needed for micro-algae (both in open ponds and in bio-reactors – or, more likely, in a combination of the two). The project also concluded that, in order to attain economic sustainability, the cultivation of algae biomass need to be aimed to the simultaneous production of biofuels and of high added value products (animal feed, aquaculture etc.).

The project conclusions built up some milestones (for scientists, industrialist and decision makers) in order to help them identifying the most appropriate strategies to develop algae-biofuels production chains. AquaFUELs identified 72 relevant algae species, 34 for biomass production, 32 for biodiesel production, 10 for bioethanol and 9 for bio-hydrogen. 30 algae species were produced commercially and 15 at pilot level and others have a potential for use as biofuel feedstock. 47 algae species were found to have a potential for cultivation in seawater and 8 on wastewater, a promising perspective due to the low impact of these culture medium on the environment. A functional taxonomy of all these algae species was created, in order to assess their suitability (in terms of biology and biotechnology) for the production of all kind of biofuels (biodiesel, bioethanol, biogas, etc.).

Finally the project started up structuring future research and scientific cooperation in the EU algae sector. Among others the project supported the creation of the European Algae Biomass Association (EABA) that already in the first months after the end of the project is taking over and carrying on most of the work that the AquaFUELs started.

In this sense the project was successful in setting the first basis for further co-ordination of research and in providing a solid future basis for industrial deployment. It is also expected that EABA, pursuing all possible applications of algae including biofuels, will be instrumental in unlocking the potential of algae for food, feed, industrial applications couples with energy applications such as biofuels.

Context and objectives

The AquaFUELs project was started at a time when the perspective of using **algae and other aquatic biomass (OAB) as innovative raw materials for biofuels production was attracting the interest of an increasing number of researchers and industrial stakeholders in the European Union and world-wide.** Such interest in most cases was related to the potential of algae and aquatic biomass to improve biofuel production sustainability performance. Indeed, one of the most critical aspects of biofuels sustainability is the way in which feedstock are produced, especially with respect to their CO_2 balance, land and water use, competition with food, and to this respect algae may provide a sensitive outlet thanks to potential high yields that they can achieve and less land requirements.

The project was conceived in order to provide a preliminary but analytical answer to all those (scientists, industrialists, decision makers) who wanted to start understanding and assessing at all levels the real potential for future biofuels production from algae. This work of analysis was performed by the Consortium partners with the three main objectives of:

1. exploring the overall feasibility of algae-to-biofuels production chains
2. indicating (to scientists, industrialist and decision makers) the most appropriate strategies to develop such production chains
3. structuring future research and scientific cooperation in the EU algae sector

In this context it was necessary, **in a first moment**, to evaluate the actual economic, technical and sustainability potential of potential large scale biofuels production pathways in order to identify their strength and their weaknesses. Since algae-to-biofuels production pathways are not well known and there is little networking among algae stakeholders, especially at European level, the objective was also to identify who are today the actors involved and what kind of development pathways are they seeking to develop. As the work was progressing it appeared also as crucial to try to set some kind of order among the various micro and macro - algal species which are today considered and studied for potential biofuels production tomorrow. In practice the work was organised around the objective of providing a **complete set of surveys** identifying actual status quo of algae for biofuels and a **complete set of assessments** (technological, economic, environmental and social) on potential algae to biofuels pathways

The above work was necessary to set the basis for the **second part of the work** to be performed in AquaFUELs, whose overall objective was to help and support scientists, industrialist and decision makers in their work to **"find the way through" for developing large scale biofuels production from algae** and/or other aquatic biomass. The main objectives in this context were **to identify future research needs** (also indicating future need for R&D projects in this field to EU decision-makers) and to **contribute to structuring the field** by means of:

a. Networking with more than 30 on-going projects (more than 64 M€) covering all AquaFUELs issues
b. Creating a European Algae biomass Association (EABA)
c. Building consensus among major stakeholders (science, industry, policy, standardization, society at large)

More in detail the work of the project was developed in order to reach number of more specific objectives, linked to the general scope and context detailed above. In the project these objectives were split in 3 main actions:

1) Understand the status quo of the European algae biomass sector and the potential of production of algae for biofuels applications
2) Identify and assess bottlenecks, research needs, sustainability impacts and provide recommendations to decision makers
3) Organise the dialogue within the scientific and pre-industrial algae biofuels sector in Europe also structuring future co-operation in the longer term (creation of an European Association of Algae Biomass)

1. Understand the status quo of the European algae biomass sector and the potential of production of algae for biofuels applications

This work was mainly to be achieved under Work package 1 of the project. An important part of the work consisted in **understanding the status quo and the potential of algae**, the activities in this perspective were mainly organised around the following points:

- It was clear as from the very beginning that for understanding the context and status quo of the EU and also – in the background - of the world-wide algae sector it was crucial to **identify, contact and list the main algae stakeholders ad their activities** via a questionnaire to be conceived and to be sent out to a very wide range of contacts. One of the difficulties was, on a first step, to find out and build up such list of contacts.

- On the other hand it was necessary to **inquire about the actual potential of algae** also setting some order about which species may indeed be suitable for biofuels production even in the medium to long term. The **identification of suitable algae species for 2nd generation biofuels** was therefore identified as another important objective to be reached. This was not sufficient: a parallel work needed to identify **the criteria for strain selection** – this was necessary in order to classify algae and other aquatic biomass according to their characteristics in terms of productivity, robustness, harvestability, biomass composition, processability/extractability, added value of co-products, local origin of strains. This work needed to be finalised by creating **a taxonomy of the most important algae species** for biofuel production

- Also **mapping the areas most suitable and therefore of interest for the production of biofuels from algae**, was included among the objectives of the project. Part of the work on the potential in fact was not to be limited to the actual bio-technology of algae strains. We realised as from the very beginning that we needed to assess in how many geographical areas a given production with a given algae strain and using a defined list of raw materials (e.g. CO^2 inflated in bio-reactors) could be realised. The mapping had to cover: natural resources for algae and other aquatic biomass, open ponds or photobioreactors for massive production of microalgae, natural blooms and wastewater streams and polluted rivers and lakes.

- As a final part of the definition of the potential of algae-to-biofuels production chains the project aimed to **detail present technologies to transform algae and other aquatic biomass in biofuels** – The types of biofuels and technologies to be inquired included**: bioethanol, biodiesel, biomethane, BTL, hydrogen, but also potential future and emerging technologies**.

2. Identify and assess bottlenecks, research needs, sustainability impacts and provide recommendations to decision makers

This work was to be achieved mainly under work package 3 of the project. The first focus was set in the need to provide a view of the **major scientific and technology research needs** for algae-to-biofuels production pathways, at four levels:

1. molecular
2. biochemical
3. cellular
4. ecosystem.

Also a complete set of assessment needed to be provided in terms of sustainability involving all angles of the concept of **sustainability for algae-to-biofuels production pathways** scenarios i.e. :

- technological sustainability,
- economic sustainability ,
- environmental sustainability , and
- social sustainability

In order to perform a more in depth analysis of algae biofuels scenarios sustainability, another objective of the project was to **verify the Life Cycle Assessment and net energy balance (NER) of the different algae and aquatic biomass-to-biofuels production pathways**. Of course the aim was not to build up a whole Life Cycle Analysis (LCA) for each algae-to-biofuels production pathways, which would have been by far exceeding the frame of the project since this kind of studies are very complex and time consuming, but rather to search the literature and start identifying and comparing the few LCAs performed until now on algae-to-biofuels technologies.

The potential **impact on developing countries** in respect of the food security and social labor implications was also to be assessed. The idea was to verify what would happen in this part of the world as a result of developing algae biofuels production on an industrial scale. Such assessment constituted another goal of the AquaFUELs project. The work was to be based on the FAO input from the FAO report "Algae-based biofuels, a report of challenges and opportunities for developing countries" (May 2009), and the last FAO report "Algae-based biofuels, applications and co-products" (July 2010). As from the beginning it appeared as essential to invite the FAO to present their point of view in October 2010 during the AquaFUELs Round Table event.

The impact on developing countries was to be studied on environment, food security, pressure on resources, and from the social point of view. The overall aim was to study it as the known impact of existing algae production, specifically in the aquaculture and food.

Finally the aim of the project was to provide some **recommendations for decision makers**, especially within the European Union and its Member States. As stated in the Technical Annex, it was aimed to contribute to build consensus on the following topics:

- Political support to the national and international research development and demonstration incentives for rapid deployment of algae-to-biofuels production.
- Inclusion of algae and aquatic biomass based biofuels in European new regulatory developments about, mainly about renewable energy and biofuels (Directive 2009/28).
- Encourage the start-up of CEN think tanks on fuel standards for algae and aquatic biomass derived biofuels and for their inclusion (in blends) in conventional diesel.

3. Organise the dialogue within the scientific and pre-industrial algae biofuels sector in Europe also structuring future co-operation in the longer term (creation of an European Association of Algae Biomass)

This work was to be achieved under work packages 2, 4 and 5 of the project. In chronological order the aim was first to organise a mid-term Round-table meeting in the project were the main experts on algae to biofuels production and related sector would have been invited.

In this perspective, in order to organise such **mid-term round table meeting** the aim was to create a contact with stakeholders, invite them to the event, then prepare in due time a call for papers, organize and manage the Round Table and finally produce a report with the proceedings of the meeting.

In order to foster dialogue in the sector the project aimed to create a network and joint **communication platform of European flagship projects signing Barter Agreement with AquaFUELs** so to exchange services for the future. Organization of synergic meetings – organization of two relevant events: the Roundtable and the Final Conference. The **establishment of the European Association on Algae (EABA)** was of course one of the main goal of the AquaFUELs that was expected to strongly support the establishment of such association. The number of organizations expected to take part at the EABA association were between 50 and 75.

Last but not least the project aimed to disseminate its results via the **creation of a visual identity for the project** (creation of AquaFUELs LOGO, EABA LOGO), this also through the build-up of the project web platform – to be activated since the first month of the project. The **participation at national and international events** to disseminate the project was also a main goal, in addition to the goal to organize and manage **the Final Conference for spreading AquaFUELs results** at the very end of the project.

Main scientific and technological findings

In this part of the final report are summarised the main scientific and technological finding of the AquaFUELs project. These findings are organised against the three main objectives that the project set as from the very beginning i.e.:

1) Understand the status quo of the European algae biomass sector and the potential of production of algae for biofuels applications
2) Identify and assess bottlenecks, research needs, sustainability impacts and provide recommendations to decision makers
3) Organise the dialogue within the scientific and pre-industrial algae biofuels sector in Europe also structuring future co-operation in the longer term (creation of an European Association of Algae Biomass)

1. Understand the status quo of the European algae biomass sector and the potential of production of algae for biofuels applications

This work was mainly achieved under work package 1 of the project. Important work and findings were linked to the actions related to the sending out and the analysis of the findings of the project questionnaire.

1.a. The AquaFUELs questionnaire

AquaFUELs sent a questionnaire to the algae stakeholders all around the world, in order to provide external input to the state of the art of biofuels. In order to maximise the rate of response, the questionnaire was divided into two parts. The first part (one page) requested only a few minutes of the respondent's time, but allowed him to provide essential information about his organisation and its activities related to algae biomass sector. The second part goes into greater details regarding the activities of the organisations in the algae biomass sector, their technologies and futures projects. Accordingly, the more committed respondents could give AquaFUELs their views on the state of the art of algae biofuels, while the shorter first part allowed other respondents to provide the essential information about them, contributing to the Who's Who Directory of algae stakeholders.

From the 622 contacts, 109 respondents (17,52%) returned a filled-in questionnaire from April 17th until June 14th, 2010. In detail, 52 respondents filled in only the first part and 56 respondents filled in both the first and the second part of the questionnaire (1 respondent filled in only the second part), which shows a high commitment to the project.

The information collected on the respondents constitutes a finding in itself, since one of the objectives of the AquaFUELs project was to map out main algae stakeholders. 83,5% of respondents were based in Europe (Israel and Turkey not included), 7,3% in the United States and 9,2% in the rest of the world, while 25,68% of respondents belonged to the industry sector and 51,37% to research and / or academia.

One of the findings was confirming the fact that the EU algae to biofuels sector is still in its infant stage, since most of interest focuses on upstream technologies. In fact to the question about the main interest in algae, 90% of respondents declared having "upstream" or "research" interests such as algae productivity, biology, technology, engineering, while the remaining part has interest "downstream" interests going beyond algae cultivation: final use of algae, advocacy of the algae industry, consultancy (*see figure below*).

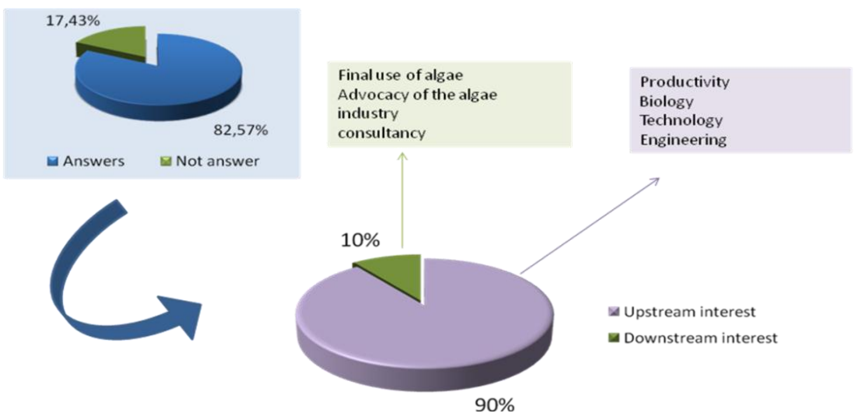


Figure 1 - Main interest

Another finding concerned the fact that it would be nonsense to think about algae biomass only in function of the production of biofuels and/or bio-energy. In fact only 11,25% of the AquaFUELs questionnaire respondents admitted to consider only energy as the final use of their product, while 73,75% of respondents considered energy to be complementary to other final uses for their product. 15% of respondents declared considering exclusively final uses other than energy.

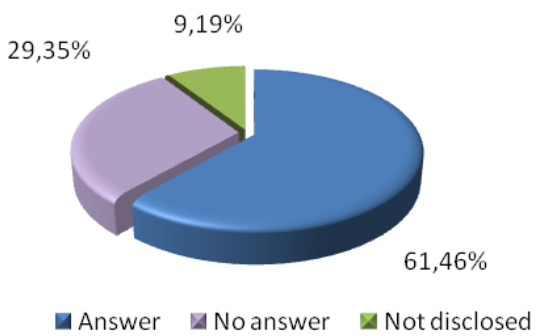


Figure 2 - Final uses

Another important finding was represented by the answers received concerning the algae strain investigated or employed sofar. The answers received reflected that the algae strains most commonly farmed were Chlorella (47,8%), Nannochloropsis (41,8%), Phaeodactylum tricornutum (26,9%), Tetraselmis (23,9%), Scenedesmus (22,4%) and Chlamydomonas (20,9%) – *see figure below*.

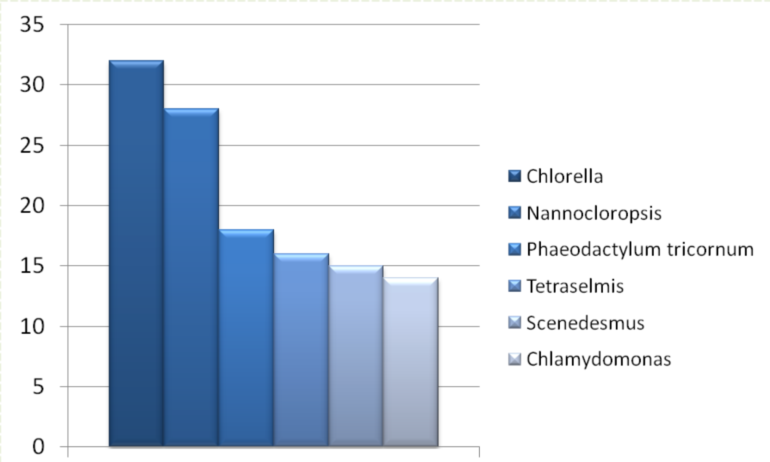


Figure 3 - Algae strains

An additional finding concerned the kind of biotechnology used in the cultivation of algae, specifically concerning the debate between the more or less suitable use of bio-reactors or open ponds. In fact it was interesting to see that this is only but a quite artificial debate given that it appeared that the main technologies used or considered are photobioreactors (60%), open ponds (6,25%) but with a necessary combination of both technologies for at least one third of the respondents (33,75%).

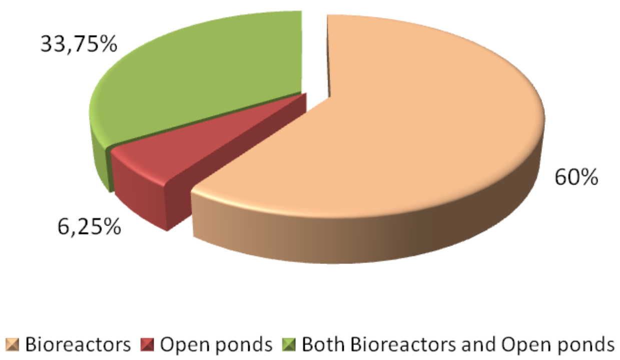


Figure 4: Bioechnology

To the open question on scaling-up limitations, most respondents replied that the lack of market or investments was constraining production, closely followed by environmental concerns. Agreement seemed to emerge on the fact that a decade of basic R&D including engineering biology, ecology, process control etc. will be required to optimize it is essential for the public sector to understand need for public funding to encourage private investments.

Another aspect highlighted was that algae production remains so far marginal in Europe: only 8 respondents produce algae and their production never exceeds 5 tons/year, which is of course very marginal if not negligible, given that the present European market for biofuels is of more than 10 million tonnes a year.

The questionnaire and especially the answers that it received and their elaboration were a very important milestone of the AquaFUELs project since it formed the basis for many other deliverables and work of the project, especially concerning the State of the art of algae biofuels. The questionnaire findings were also instrumental in the development of the European Algae Biomass Association (EABA).

The aim of this questionnaire was also to put the first stones in order to create a **Who's Who Directory and Survey on algae stakeholders at European and international level**.

1.b. Who's Who Directory of algae stakeholders

From a broader perspective, this survey aims to be a simple, clear and practical tool for algae stakeholders by putting together all members of the emerging algae community. The findings of the AquaFUELs questionnaire were the main source for this work of listing Major Stakeholders, as all the Questionnaire respondents were included. The creation of an initial directory of the main algae stakeholders in Europe and in third countries was immediately identified as a fundamental need for understanding who the main actors are in the European and international algae biomass industrial and scientific sector.

Following a different approach for scientific and industrial stakeholders, the final report realised on main stakeholders includes:

- for scientific stakeholders, a personal photograph, personal contact details and an indication of the fields of expertise and the participation in research projects (EC-funded or other);
- for industrial stakeholders, the company logo, a precise description of the company's interest in algae (mainly distinguishing between technology providers, producers and end users) and the exact nature of its activities.

After the presentation of the questionnaire results, it became apparent that not all actors potentially relevant for a directory of important stakeholders were to be found among questionnaire respondents and that the survey had not captured some of the most eminent stakeholders in Europe. Following these discussions a new set of stakeholders was added, leading to the final version of the deliverable. The final report on main stakeholders included 418 stakeholders in total, well exceeding the targeted 250 entries mentioned in the objectives of the Technical Annex, including 88 European Industrial Stakeholders, 124 Non-European Industrial Stakeholders, 163 European Research/Academia Stakeholders and 43 Non-European Research/Academia Stakeholders.

It was interesting to observe that most of the 163 European Researchers and Academia are located in the UK (52 researchers). As for industry players, Belgium (18), France (16), Italy (14), Spain (14), Germany (14), appear ahead of other European countries. From the 43 Non-European Research/Academia Stakeholders, the US (9), India (6) and Israel (6) have the greatest amount of stakeholders, even if research appears to be taking place in all continents.

Figure 5 - European Research/Academia

Figure 5a - Non-European Research/Academia

In addition to the work implied to complete the project, the directory of stakeholders assembled by AquaFUELs was transferred to the European Algae Biomass Association (EABA). Indeed, the need for an overview of the nascent algae sector and for further structuring of the algae community was felt by the organisation representing the algae sector in the same way as by the AquaFUELs project partners. This development, although initially unforeseen, was in line with the project objectives, as the support to the establishment of the European Algae Biomass Association was one of the project milestones and a key dissemination action (Task 5.4/ Milestone 4.2).

Continuing the work initiated by AquaFUELs, **EABA updated the directory regularly**, with a view to contribute to the Who's Who directory of algae stakeholders. Therefore, EABA took over the directory started with the questionnaire (111) and the report on main stakeholders (419) and increased the database of stakeholders **to finally exceed one thousand stakeholders (1042) in June 2011, when AquaFUELs formally ended**. Further work will still be carried out by EABA to refine the database and add new contacts, with a view to present the Who's Who directory of algae stakeholders at the EABA Conference in November 2011.

Building up on the AquaFUELs work, the EABA is now able to make an essential further step towards a genuine Who's Who directory of algae stakeholders, which was in line with the objectives of AquaFUELs: refining the database and distinguishing between genuine algae stakeholders and less credible organisations. Indeed, the innovative yet promising nature of algae biofuels has been accompanied by the emergence of actors making unrealistic claims, as noticed several times by AquaFUELs partners. The nature of EABA as the organisation of the algae sector in Europe will be instrumental in achieving this aim, and would not have been possible without the further work done by AquaFUELs.

1.c. Selecting algae suitable for biofuels production

The report on algae taxonomy was realised in order to advance the understanding of algae taxonomy, biological and biotechnological aspects in a perspective functional to future biofuels production.

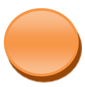
The AquaFUELs work on taxonomy was based on the suitability of micro-organisms for biofuels production rather than on strict botanical classification.

Given the high complexity of algal taxonomy and evolutionary relationships, the work on taxonomy was conceived as an instrument to place the algae that have arisen an interest for biofuel production within the correct frame. The list of algae proposed is based on the literature concerning biofuel production, on the commercially produced algae and on the feedback from the questionnaire in deliverable 1.1.

It was beyond the scope of the work on taxonomy to propose any kind of new or revised taxonomy of algae. The classification reported is based on AlgaeBase (http://www.algaebase.org/) and Tree of Life project (http://tolweb.org/tree/). Also some other aquatic biomasses species were reported which are all invasive weeds that have been proposed as biofuel crops.

In this respect, AquaFUELs went beyond the traditional view, which considers algae as water-dwelling photoautotrophic unicellular or multicellular organisms classified according to the nature of their photosynthetic pigments, storage products, cell wall, presence or absence of flagella and the number of membranes surrounding the chloroplast. Indeed, prokaryotic blue-green algae, or cyanobacteria (Class Cyanophyceae), and some cyanobacterial species (*Arthrospira* or spirulina) have often been considered as algae due to their prominent position in the biotechnological exploitation of microalgae.

72 algae strains relevant to biofuels were identified: prokaryotic microalgae (cyanobacteria), eukaryotic microalgae, macroalgae and aquatic plants. Based on the list of algae having a potential for biofuels production, AquaFUELs produced individual factsheets for each specific algae strain, including reader-friendly markings allowing to identify quickly which algae would have a potential and the current state of research for that specific algae strain. These factsheet were produced based on the work carried out on taxonomy, biology and biotechnology to provide all the information on a specific alga in a reader-friendly way (as shown in the figure below):

SYMBOLOGY of the level of use of the alga	
	This symbol indicates that the alga has a potential application and is currently used at pilot experimental level for biofuels
	This symbol indicates that the alga has a potential application for biofuels, though there is no pilot production
	This symbol indicates that the alga is commercially produced and available in large quantities

D	Potentially interesting for biodiesel production
E	Potentially interesting for bioethanol production
H	Potentially interesting for biohydrogen production
B	Interesting for biomass production
PIV	Pivotal taxon for biotechnology description

Figure 6 – Reader-friendly tags used for algae taxonomy

The factsheet created for every algae strain includes the most commonly accepted botanical name, pictures of the algae to allow easy recognition, the references to the state of research and the potential uses, taxonomical classification and related species. In the (cropped) factsheet shown below, *Haematococcus pluvialis* is indicated as being currently commercially produced, interesting for biomass production and as being a pivotal taxon for biotechnological description. Among the species identified, a difference was made between pivotal species, for which extensive factsheets were developed, and secondary species for which the main parameters only were addressed.

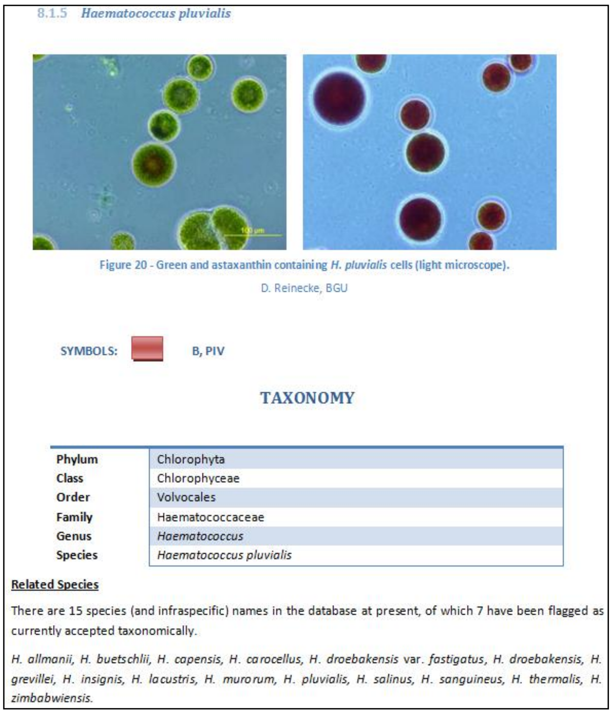

8.1.5 *Haematococcus pluvialis*

Figure 20 - Green and astaxanthin containing *H. pluvialis* cells (light microscope).

D. Reinecke, BGU

SYMBOLS: B, PIV

TAXONOMY

Phylum	Chlorophyta
Class	Chlorophyceae
Order	Volvocales
Family	Haematococcaceae
Genus	*Haematococcus*
Species	*Haematococcus pluvialis*

Related Species

There are 15 species (and infraspecific) names in the database at present, of which 7 have been flagged as currently accepted taxonomically.

H. allmanii, H. buetschlii, H. capensis, H. carocellus, H. droebakensis var. *fastigatus, H. droebakensis, H. grevillei, H. insignis, H. lacustris, H. murorum, H. pluvialis, H. salinus, H. sanguineus, H. thermalis, H. zimbabwiensis.*

Figure 7 – Extract from the Taxonomy – reader-friendly factsheet for Haematococcus pluvialis

Based on a merging of the work achieved under the project on taxonomy, biology and biotechnology, a single document was realised (going beyond the initial objectives of the project) merging all the taxonomical, biological and technological information for each algae strain.

This document regarding algae suitability for biofuels production became a reference merged report on taxonomy, biology and biotechnology. This allowed the project to produce a table summarising the salient aspects of the 72 algae strains identified, in order to allow easier identification of the respective algae and their potential for biofuels production. In the table, the algae species considered as pivotal for further studying the potential of algae appear in bold, as highlighted in the example below:

Algae species	**Potential use**	**Status**	**Comments**
Alaria esculenta	Biodiesel	Pilot Commercial	Macro-algae. Can be grown in seawater.
Amphiprora hyalina	Biodiesel	Potential	Can be grown in seawater, brackish water. Forming biofilms. Lipid content 22%-37%. Require specific photobioreactors.
Amphora sp.	Biodiesel	Potential	Can be grown in seawater, forming biofilms. Composition varies with light, indoor/outdoor, culture medium. Lipid content 26-81%. Require specific photobioreactors.
Anabaena sp	Biohydrogen	potential	Small-scale experiments performed successfully over one month
Ascophyllum nodosum	Biomass	Pilot Commercial	Macro-algae. Can be grown in seawater. Harvested from the wild and used as fertilizer, plant growth promoter and for alginate production. 30,000 tons/year are produced.
Botryococcus braunii	Biodiesel	Small-scale commercial	Colonial microalga, produces lipids and hydrocarbons up to 60% of biomass during exponential growth, not under stress, easily contaminated in outdoor culture

Figure 8 - Conditions of robustness.

Out of the 72 algae species identified, 34 are relevant for biomass production, 32 for biodiesel production, 10 for bioethanol and 9 for biohydrogen. 30 algae species were produced commercially and 15 at pilot level, while the remainder had a potential for use as biofuel feedstock. Several strains were tagged with different statuses in order to account of the different stage of technological advance for their different possible uses, e.g. *Undaria pinnatifida*, whose commercial production for food is tried and tested, while its potential for bioenergy has only been partially investigated. 47 algae species were found to have a potential for cultivation in seawater and 8 on wastewater, a promising perspective due to the low impact of these culture medium on the environment, in particular for macro-algae.

Generally, the reports intended to identify algae species suitable for biofuels production resulted in a list of algae with a potential for biofuels production with experiments at pilot scale at best, with the notable exception of *Botryococcus braunii,* cultivated at small scale for biodiesel production. However, it cannot be ruled out that private research still remaining confidential might have resulted in additional breakthrough towards commercial production of certain algae species, such as *Prototheca sp.* (Solazyme), Benthic diatoms (SBAE) or *Botryococcus braunii* (Algafuel). Regarding algae strains currently produced for other uses than energy, the state of the industry must be considered as promising, but not necessarily implying that a conversion to algae production for bioenergy would be a straightforward operation. Indeed, algae composition was found to vary according to cultivation factors, since stress was found to increase the content in certain metabolites and because algae can change their activities according to the state of their development. Further research in scaling-up, outdoor cultivation and year-round production is needed before the potential of many algae can be confirmed. AquaFUELs found that according to the current state of the art, no algae species represents a straightforward solution for massive production of algae with a view to produce algae biofuels, although certain algae species could be considered close to market readiness due to the advanced state of research in biology and biotechnology.

An additional finding from the report on biotechnology has been that the specific feature of an algae are essential factors ensuring its potential commercial production, e.g. tolerance to different culture medium, robustness or thin cell wall. AquaFUELs identified criteria for strain selection for other algae strains to be rightly considered as having a potential for biofuels production:

- **Productivity**. Photosynthetic efficiency is an efficient measure of productivity, i.e. the % of available light (energy) converted into biomass, which allows comparison between all algae species;
- **Robustness**. This broad criteria reflects the ability of algae to resist challenging conditions;

Condition	Relevant for	Range
pH	Reduce risk of infection CO2 transfer	**i.e. <4 and >10**
Oxygen concentration	Closed photobioreactors	**>20%**
Temperature	Outdoor cultivation Open water cultivation	**Large range to accommodate day/night and seasonal fluctuation (e.g. 10 – 40 °C)**
Salinity	Cultivation in fresh / sea / brackish water	**e.g 0-10% salinity**

	Reduce risk of infection	
Organic contaminants	**Ability to grow on wastewater / flue gas**	**Concentration of organic contaminants that still allows good growth**

Figure 9 - Robustness

- **Harvestability**. Sedimentation rate and the possibilities for induced- or auto flocculation for microalgae, possibility of mechanical/hand harvesting for macroalgae;
- **Biomass composition**. Total energy content, % lipids/% starch and suitability for biofuel production, possible co-products, % protein, presence of heavy metals/toxins;
- **Processability**. Cell thickness, fiber content, moisture;
- **Value of co-products**. Valuable compounds produced alongside these relevant for biofuels
- **Local origin of strains**. Adaptation to their likely outdoor culture conditions.

1.d. Algae suitability for final biofuel production

The main finding of the project in this area was that, as of today, none of the biofuel production pathways identified in the project for transforming algae into a biofuels currently qualifies as an economically viable biofuel production process. A biofuel can be economically viable and sustainable if the energy required to drive the process to obtain the final biofuel does not exceed the energy that is generated by the biofuel, but many of the algae-to-biofuel production processes need to be improved in order to decrease the energy input and therefore their economic viability.

Using algae as feedstock for current biofuels ensures that the final processing is comparatively still lower-cost, tried and tested technology with established downstream production chains and even the effective integration to fuel markets – an important aspect since supply chains may not exist for all advanced biofuels, hindering their market penetration. Future technologies as hydrogen production and BTL techniques would still require adaptation on downstream markets, making them less desirable biofuels pathways for algae as compared to other pathways. However, several technical arguments tend to support these pathways: physico-chemical characteristics of the final fuels similar to these of fossil fuels, allowing easy integration to the distribution infrastructure and to vehicle design, potentially opening the doors of the jet fuel market. In this respect, algae biofuels produced by hydro-treating algae oils should be considered on an equal footing with biodiesel production, due to similar production costs, while BTL technologies have proved to be highly costly. Although inexpensive, the production of biogas or biohydrogen in fermenters from algae may have low yields, making it an option for small and de-centralised energy production units rather than for industrial production. However, biogas can be produced from a wide array of possible biogas lagae feedstock, making it a possible option for the valorisation of co-products from other pathways and more generally a flexible solution for algae conversion to energy. Biohydrogen from algae is still far from commercial production and although photofermentation seems promising, the need for an organic medium and significant inputs to cultivate these algae makes their sustainability questionable. Thermochemical liquefaction allows bypassing the traditional hurdles of harvesting and extraction, which is technically promising. However, additional research is required for this pathway, which is also energy-intensive and thus questionable in terms of economic and environmental sustainability.

As a main finding of the AquaFUELs project was realised a table (*see below*) summarising the various characteristics of each different algae-to-biofuel production process.
Number of parameters is used in order to benchmark each different algae-to-biofuels production pathway.
The parameter "**Suitability for algae**" reflects the biofuels pathway's ability to use the natural characteristics of the algae, e.g. carbohydrate accumulation for bioethanol or wet content for thermochemical liquefaction. Cost-effectiveness mainly depends on the input required and on the current technical command of this pathway within the biofuels industry. **Sustainability** mainly refers to greenhouse gas (GHG) life-cycle emissions, reflecting either demanding cultivation conditions for certain algae or the high GHG emissions from certain processes. The results for **cost-effectiveness** and **sustainability** are similar as they depend on the input needed, except for bioethanol: the CO2 released during the fermentation process makes ethanol production less sustainable than other pathways, while on the opposite algae yielding directly bioethanol remove the need for energy-intensive harvesting and extraction. The early stage of development of most pathways or their functional limitations are reflected through "**scaling-up potential**", for which only current biofuels can be deemed to have no potential scaling-up limitations. "**Ease of extraction**" mainly reflects the need for extraction specific to the production of biodiesel, bioethanol and HVOs. Extraction adds to the process complexity. Similarly, "**Ease of conversion**" mainly reflects the complexity of BTL pathways. The possibilities for co-products valorisation are necessarily negative for pathways using the whole algae. The difference between "**final fuel characteristics**" and "**end market suitability**" is the following: a process can yield a fuel adapted to a market, but mixed with so many other co-products that further refining or purification is required. The need for downstream infrastructure and vehicle adaptation is reflected in "**end market suitability**".

	Suitability to algae	Cost-effectiveness	Sustaina-bility	Scaling-up potential	Ease of extraction	Ease of conversion	Co-products valorisation	Final fuel characteristics	End market suitability
Biodiesel	+	+	+	+	-	=	+	+	+
Bioethanol (starch extraction)	+	+	=	+	-	=	+	=	+
Bioethanol (direct production)	=	-	+	-	+	+	+	=	+
Biogas	+	+	+	+	+	+	+	-	-
Biohydrogen (water pyrolysis)	=	+	+	-	+	=	=	-	-
Biohydrogen (photofermentation)	=	-	-	-	+	=	=	-	-
Biohydrogen (dark fermentation)	=	+	+	-	+	=	=	-	-
BTL (pyrolysis)	-	-	-	=	+	-	-	-	+
BTL (thermochemical liquefaction)	=	-	-	=	+	-	-	=	+
Hydrotreated vegetable oils	=	=	+	=	-	=	+	+	+

Figure 10: All indications should be read with biofuels production as a final objective, i.e. a + reported in the column "co-products valorisation" means that this pathway offers co-products valorisation options. Blue reflects positive aspects, red accounts for negative aspects and white corresponds to a neutral result.

1.e. A main finding of the project: the important potential of macroalgae for biofuels production in the short to medium term

One of the main findings of the project is that among biofuels from algae, macro-algae use as a feedstock for biogas or bioethanol production would show the greatest potential in the short to medium term.

Macro-algae can be grown in seawater at large-scale, as largely demonstrated in Asia, where a deep-rooted industry has been produced in massive quantities since the 1960s (4.9 million tons/year for *Saccharina latissima* and 2.4 million tons/year for *Undaria pinnatifida*) following tried and tested methods.

Although a macro-algae industry could emerge, production at large scale remains to be demonstrated in Europe and the development of macroalgae farms at sea represents the main technological bottleneck. Pilot plants reflecting the conditions of commercial production, including siting, could allow confirming the scaling-up potential of algae cultivation. Only 2 pilot plants for macro-algae (laminaria) currently exist, to be connected to wind farms. Laminaria, containing 60% fermentable sugars, is well suited to biogas and bioethanol production and a bio-refinery approach could allow valorising valuable co-products.

As opposed to microalgae, macroalgae are easier to harvest and harvesting can be performed by hand or mechanically. This distinctive advantage removes the energy-intensive harvesting and dewatering phases (as well as extraction in the case of biogas), making macroalgae biofuels more environmentally sustainable or economically viable than biofuels from microalgae.

In the perspective of mass macroalgae production at sea, the interaction of large scale algal cultivation on its immediate surrounding area should be assessed, both from the point of view of possible environmental contamination and concerning possible contamination from unwanted organisms decreasing productivity. However, it has been highlighted by AquaFUELs that the semi-wild culture conditions of macro-algae were likely to have a low impact on the environment. Similarly, these culture conditions imply a low cost, provided that mechanisation can be involved or low-cost labour in the case of harvesting by hand. Cultivation and also harvesting from the wild could be employed, provided that harvesting takes place in a sustainable way. However, it has been stressed by AquaFUELs that although biogas or bioethanol production from macro-algae could contribute to removing polluting macroalgae blooms from the sea and water streams, algae blooms would not constitute a satisfactory option for industrial exploitation due to their variable location, composition and quantity.

Macro-algae conversion to biogas or bioethanol appears the most realistic perspective, as the production processes of these biofuels are compatible with a wet feedstock. For biogas and bioethanol, the final fuel quality is not affected by the origin of the feedstock, as opposed to biodiesel, putting macroalgae on the same footing as other feedstocks. However, the low development of the biogas industry in Europe and the wide array of feedstock available for bioethanol production decrease the likeliness of macro-algae biofuels to be picked up by market players.

No LCA for macro-algae are available in the literature, although a number of research projects are expected to publish on this subject in the near future. It is thought that LCAs will improve the rationale behind each step of biofuel production and therefore give a key to the least harmful and most efficient way of producing biofuel from macroalgal biomass.

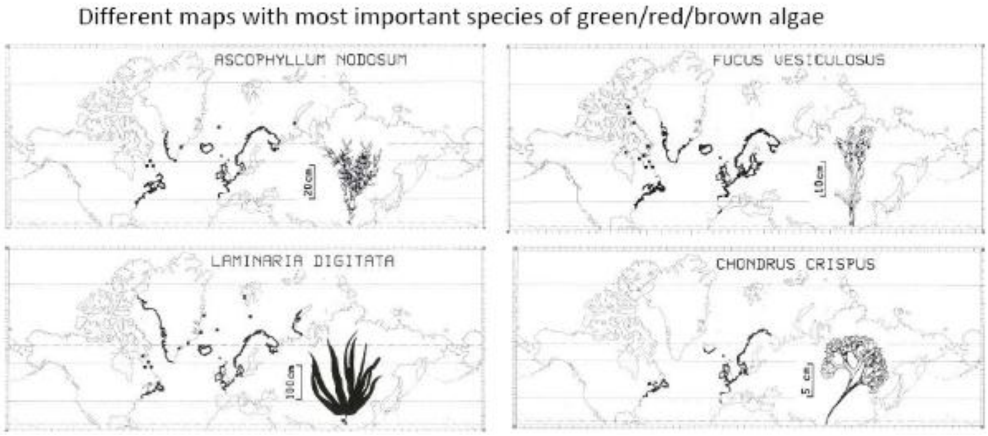


Figure 11 – Relevant macroalgae for cultivation in Europe

1.f. Mapping of potential algae to biofuels resources

Finally, from the researches carried on for task 1.9, the deliverable **D 1.6 *Mapping*** was delivered including the main results on this topic.
Working on this report confirmed the general impression that it is an almost impossible challenge to map the locations where all needed resources are present or could be easily/cheaply provided. Very few locations exist where all features are ideal, since a lot of the requested characteristics are in conflict with each other, such as proximity to industrial CO_2 or waste water, but not enough space for hundreds of hectares of cultivation site. Resource proximity has impact on the economics of algae production. Integration of algae cultivation with other sectors (e.g. livestock raising,...) will be necessary to make it economically profitable.
The **potential highest yield for algae biomass is in warm countries close to the equator**. Typically these high yield areas have also lower costs for land and labour. However, the regions identified as being most suitable for year round large scale production systems have e.g. very few large CO2 emitters in close proximity and are not always close to a water supply.
At higher latitudes more nutrient sources and CO_2 point sources are available. However, lower temperatures and lower solar radiation impair year-round cultivation.. Local natural species may be identified that are productive in these climates.
It is also quasi **impossible to generalize in choosing a perfect location for algae cultivation**. Most algae species have different optimal growth conditions and even these can differ within one species depending on the requested end product (see 1.4 Biology and Biotechnology). So when the preferred species for cultivation is identified, the most optimal location should be mapped taking into account

the species' optimal growth conditions and a much more detailed mapping of the best geographical potential for algae biomass production will be determined.

2. Identify and assess bottlenecks, research needs, sustainability impacts and provide recommendations to decision makers

This work was to be achieved mainly under work package 3 of the project. The first focus was set in the need to provide a view of the **major scientific and technology research needs** for algae-to-biofuels production as well as a complete set of assessment needed to be provided in terms of sustainability involving all angles of the concept of **sustainability for algae-to-biofuels production pathways** scenarios i.e. :

- technological sustainability
- economic sustainability
- environmental sustainability and
- social sustainability

2.a. Scientific findings on research needs.

Most of these studies were carried out under task 3.1, the main finding that emerged is that despite being a potential source of renewable fuels, the production capacity for microalgae is presently limited in comparison to land based energy crops. The current worldwide microalgal manufacturing infrastructure (producing the equivalent of approximately 5000 tons of dry algal biomass) is devoted to extraction of high-value products such as carotenoids and ω-3-fatty acids used for food and feed ingredients.

The total market volume is €1.25 billion, implying an average market price for microalgae of €250/kg dry biomass (Pulz and Gross 2004). As an example for comparison with land based oleaginous crops, the world production of palm oil is nearly 50 million tons with a market value of approximately 0.50 €/kg (faostat.fao.org). Production of microalgae for biofuels needs to take place on a much larger scale at much lower costs. If all transport fuels were to be replaced by biodiesel in Europe, there would be an annual need for nearly 0.4 billion m3 (IEA). If this biodiesel were to be supplied through microalgae, 9.25 million ha (almost the surface area of Portugal) would be needed in order to supply the European market, assuming a productivity of 40,000 litres per ha per year. This productivity is based on a 3% solar energy conversion to biomass (theoretical maximum is 9%) and a biomass oil content of 50%, under the solar conditions of Portugal. A leap in the development of microalgae technology is therefore required; on a practical level, the scale of production needs to increase at least 3 orders of magnitude with a concomitant decrease in the cost of production by a factor 10 (Norsker et al 2010).

In the past few years there has been a rather polarized debate between researchers in the field about technology readiness and the prospects for productivity enhancement, with some parties pressing for scale-up and commercialization now, while others cautiously stress the need for additional research leading to more careful step-by-step development (Wijffels and Barbosa 2010). Production of microalgae for co-production of biodiesel and bulk chemicals can become economically feasible. If the technology develops we expect that the cost price of production of microalgae will reduce gradually. Microalgae are now produced for high-value products in niche markets, however, if the cost price of production goes down it is expected that with every step in reduction new markets will open. Initially most probably production of edible oils for food and fish feed will become feasible, but after some time also production of bulk chemicals, biomaterials and biodiesel may become feasible. For that the technology needs to develop from a small size activity to an industrial scale technology.

We expect that such a development will at least take 10 years. For that a multidisciplinary approach needs to be developed and integrated research is required at several levels.

2.b. Technological assessment including downstream added value products.

This work combined the work done in two tasks of the Aquafuels project: a technological assessment of the major bottlenecks in cultivation, harvesting and extraction of biofuels and an overview and description of the possible valuable byproducts that increase the overall value of algal biomass.

The technological assessment gives a brief overview of the current state of the art and indicates where the main technological bottlenecks are that remain to be overcome in order to make large scale utilization of algal biomass for biofuels economically feasible. The main process steps cultivation, harvesting and extraction are discusses separately for microalgae and macroalgae since there are intrinsic differences between them on all aspects of the process. Finally the technological aspect of the refinery into high quality fuels is discussed.

In the second part and overview of byproducts from both micro- and macro algae was given and their applications are discussed. High-value byproducts increase the overall value of algal biomass and increases the economical potential of algae as a multipotent resource for a biobased economy. Much like crude oil is refined in both fuel and fine chemicals, the value of algae is greatly increased if the parts of the biomass that cannot be converted into fuels are utilized for food, feed, chemicals, cosmetics, biomaterials or even pharmaceutical applications.

2.c. Algae biofuels sustainability

For biofuels, sustainability issues have been extensively discussed and mandatory sustainability criteria have been set out for biofuels as part of the Climate Energy Package, published in 2009. Accordingly, all biofuels placed on the market in the European Union will have to demonstrate sustainability, making a prominent issue for algae biofuels. This section will also address economic sustainability.

I. Microalgae – Lifecycle Assessment

There have been many attempts to estimate the energy and carbon balance of micro-algae biofuels production using life cycle assessment (LCA). If micro-algae are to be a viable feedstock for biofuel production then the overall energy balance must be positive. As no industrial scale processes designed specifically for micro-algal biofuel production yet exists, the data that underpins micro-algae LCA must be extrapolated from laboratory scale systems and from commercial schemes that have been designed for other purposes. AquaFUELs used simple a meta-model to normalise boundaries and assumptions for the cultivation, harvesting and oil extraction stages. In all cases the primary energy input for the normalized process is equal to, or less attractive than, the original case. It is also noticeable that the closed systems, especially tubular PBR, demonstrate poor energetic performances compared to raceway ponds, as shown in the table below.

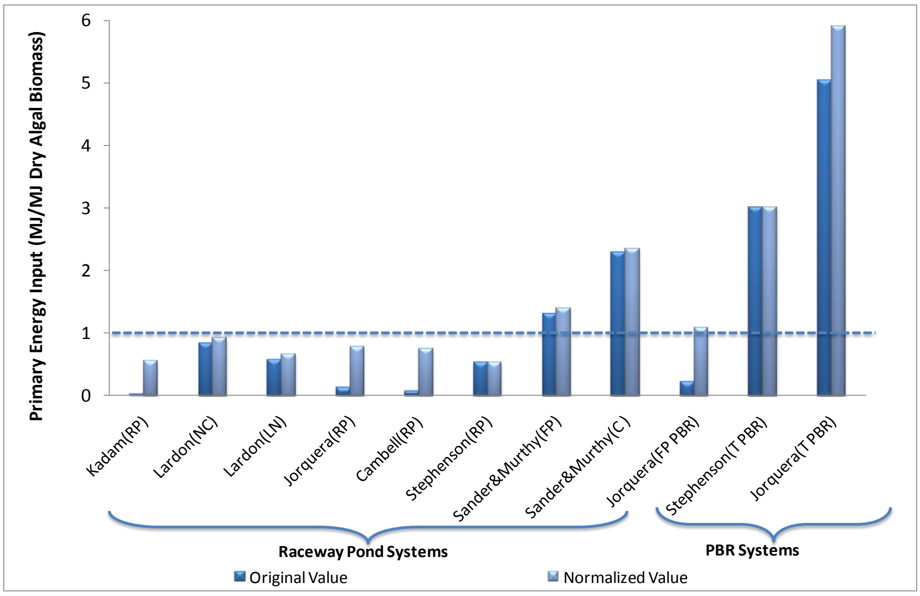


Figure 12 - Net energy ratio for micro-algae biomass production

The majority of emissions are associated with electricity consumption and heat used to dry the algae. Notably, emissions associated with algal biomass production in raceway ponds are comparable with the emissions from the cultivation and production stages of rape methyl ester biodiesel. Production in PBRs, however, demonstrates emissions greater than conventional fossil diesel.

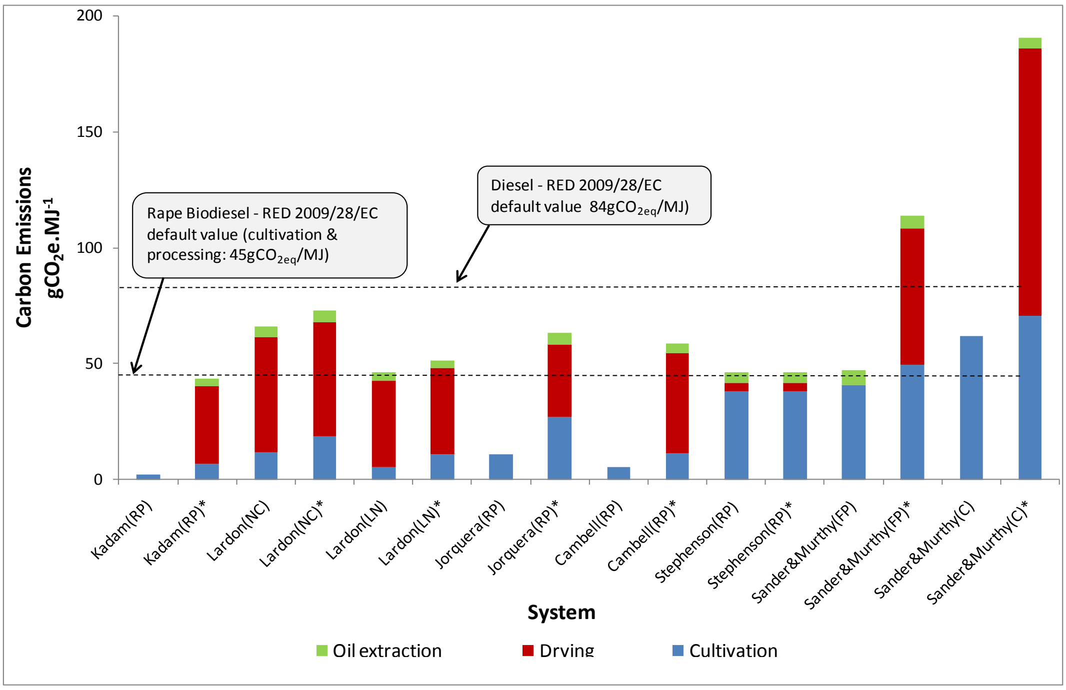


Figure 13 - Illustrative estimates for CO2 emissions from raceway ponds

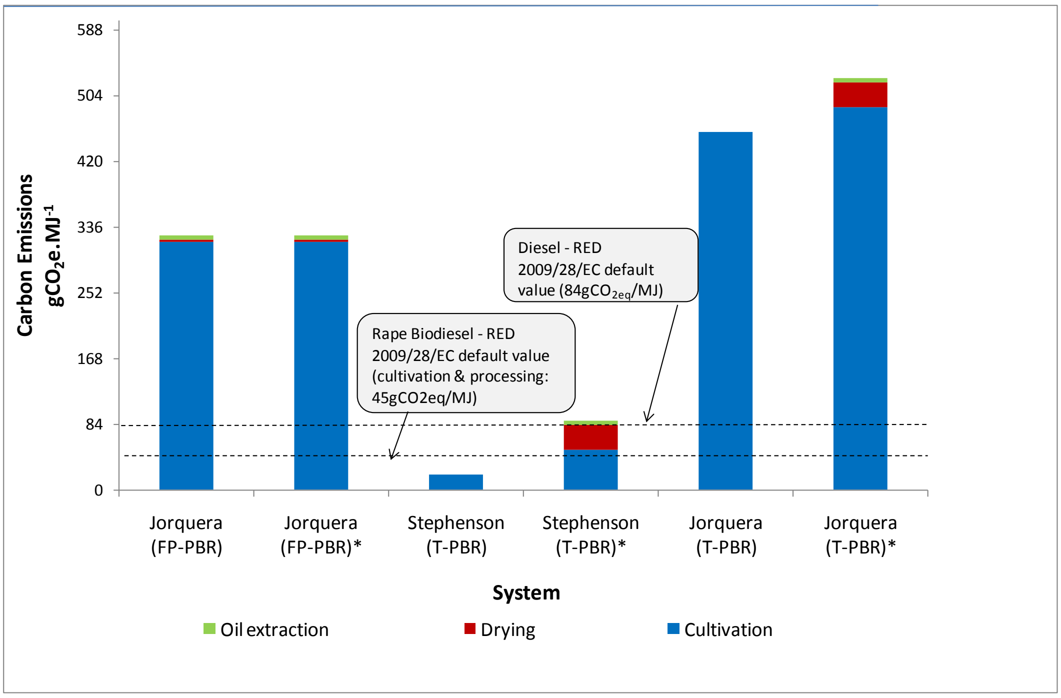


Figure 14: Illustrative estimates for CO2 emissions from photobioreactors

Although data cannot be regarded as fully reliable, the analysis supports the following conclusions:

- Raceway Pond Systems demonstrate a lower (more desirable) NER for both biomass and lipid production than PBR Systems;

- The NER for biomass production in the normalized system described is unattractive, or at best, marginal. This indicates that algae production may be most attractive where energy is not the main product;
- The most optimistic NER values for algae production come from the systems that are the least complete. The addition of additional process steps makes the NER less attractive in all cases;
- The carbon emissions from algae biomass produced in raceway ponds is comparable to the emissions from conventional biodiesel;
- The carbon emissions from algae biomass produced in PBRs is greater than the emissions from conventional diesel. The principle reason for this is the electricity used for pumping the algal broth around the system;
- While the meta-model includes some additional process steps, others might also reasonably be included in a complete system. These include: the energy embodied in chemical flocculants and hexane loss during harvesting and lipid extraction. In hot climates PBRs may also require cooling. The addition of these processes would make the NER less attractive;
- There is a significant variation in the energy consumed in the cultivation and harvesting phase per MJ algae (biomass or lipid) produced. Key assumptions that affect this are the productivity of the algae, its calorific value and lipid content (assuming both a high productivity and high lipid content may be over optimistic);
- Assumptions in the original studies are often obscure, or open to interpretation. For example, one of the studies (Kadam 2002) includes less nitrogen as an input than is contained in the algae output. This may be an oversight, or the authors may have made some additional assumption that is not explicit: it is possible that the missing nitrogen may be recycled or come from some other source;
- Algae production requires a number of energy demanding processes. However, within the LCA studies considered here there is no consistent hierarchy of energy consumption. Aspects that will need to be addressed in a viable commercial system include: the energy required for pumping, the embodied energy required for construction, the embodied energy in fertilizer, and the energy required for drying and de-watering.

II. Microalgae – Environmental Assessment

Micro-algae production could have a wide variety of environmental impacts beyond the consumption of energy in the production process:

- A reliable, low cost water supply is a critical factor in the overall success of biofuel production from micro-algae, as fresh water needs to be added to raceway pond systems to compensate water evaporation and also for cooling Closed Systems (PBRs);
- Algae production could use marginal land, and thus would entail little additional competition on land required for food production;
- Algae cultivation requires several fertilizers, primarily Nitrogen (N), Phosphorus (P) and Potassium (K);
- Algae cultivation requires a source of carbon dioxide as producing 1 kg dry algal biomass requires at least 1.83kg CO_2. If CO_2 from flue gas were used, the cost would decrease and industrial emissions could be mitigated, but managing these gases could have negative effect

on the energy balance of the system, it may also be restricted for health and environmental reasons;

- Algae are quite sensitive to temperature, and maintaining a high level of productivity could also require temperature control. Heating and cooling could require additional fossil fuel and the environmental performance could, however, be improved by system integration that to utilize the waste heating from power generation for drying the algal biomass;
- Pollution by nutrients, termed eutrophication, can be improved or worsened by algal aquaculture, e.g. if culture medium is leaked into local aquatic systems. Positive impacts could occur if algae production were to be integrated into the treatment of water bodies already suffering from eutrophication. Similarly, algal toxicity can have a negative impact on the environment;
- GMO cannot be contained in open systems, culture leakage and transfer in unavoidable.

Micro-algae culture can have a diverse range of environmental impacts. Many of these impacts are location specific, e.g. water and land use. Impacts such as the use of genetic engineering are uncertain, but may affect what systems are viable in particular legislatures.

III. Microalgae – Economic Assessment

Existing cost assessments are hypothetical in nature, reflecting outdated data or future aspirations rather than currently achievable results. In addition, the production of co-products, or provision of co-services, greatly affects estimates of economic viability. Therefore, the results are likely underestimate the true cost of algae production. The future scenarios also postulate dramatic improvements in technical performance that may, or may not, be achieved. With these important caveats in mind, we consider that this analysis supports the following conclusions:

- Raceway pond systems demonstrate a lower cost of algal biomass production than photo-bioreactor systems;
- Most of the costs in raceway system production are associated with operation (labour, utilities and raw materials). The cost of production in PBRs, in contrast, is dominated by the capital cost of the PBRs;
- Dramatic improvements in both productivity and energy efficiency would be required to greatly reduce the cost of biomass production;
- Significant (>50%) cost reductions may be achieved if CO_2, nutrients and water can be obtained at zero cost. This is a very demanding requirement, however, and it could dramatically restrict the number of locations available;
- biofuels could not be the only end market, co-product and co-service valorisation would be essential;
- Many opportunities to reduce costs exist though improved engineering and biotechnology.

Cost assessments of micro-algae production are at an early stage of development. They are appropriate to guide engineering development, and test the sensitivity of design assumptions, but they are insufficient to guide policy or investment decisions in anything but the broadest of terms.

IV. Macroalgae – Lifecycle Assessment

No detailed LCA for the energy and carbon balance of macro-algae exist, due to a lack of data with which to populate the models, and, until recently, a relatively low level of interest.

V. Macroalgae – Environmental Assessment

Macro-algae production could have a wide variety of environmental impacts:

- Space in the near-shore coastal environment is likely to be limited, while cultivation further offshore is possible but brings additional challenges and costs;
- Freshwater requirements for production of marine macroalgae are minimal;
- Fertilisation at sea is not an acceptable option, while the high capacity of kelps to remove inorganic nitrogen and phosphorus from the environment makes them potential nutrient 'scrubbers' ;
- Strain selection is considered vital to development of an economically viable industry;
- Cultivation at sea could lead to the dominance of one species and a collateral decrease in ecological quality;
- The scale of the harvest from the wild can leave the complex kelp ecosystem unaffected or have unknown but possibly massive consequences;
- Harvesting blooms is associated with increased greenhouse gas emissions and is an unreliable source of feedstock.

2.d. Potential and impact in developing countries

The main findings of the project in this respect were confirming that developing countries could play a specific role in the future of algae biofuels, as potential producers, consumers or suppliers to the developed economies. It should also be borne in mind that several developing countries, including China and India as well as other economies in Southeast Asia, can actually be regarded as more advanced than developed countries when it comes to large-scale algae cultivation, in particular macro-algae.

However, the development of algae production facilities for food or feed had so far avoided the issue of harvesting and extraction, which represents a significant bottleneck for developing countries as well as for developed countries. In this respect, developing countries may have an advantage over developed countries, as low labour costs allows more labour-intensive harvesting and extraction techniques, which could contribute to a less energy-intensive process and therefore improve both economic and environmental sustainability.

Although tropical climates can be considered as an asset, in particular for low-cost open ponds technologies allowing to use the temperature and sunlight from the environment, the limited investment and R&D capacities can represent an issue for an industrial process where technological bottlenecks can be expected to play a major role for market development in the coming years.

Similarly to other biofuels, algae biofuels could help fighting the forthcoming energy scarcity, which will affect developing countries to an even greater degree than developed economies. In this respect, algae biofuels could represent the only way to maintain effective transport systems in countries in lack of infrastructure and to allow continued agricultural development. Algae cultivation in developing countries could allow mitigating or using the potentially negative effects of pollution and global warming by removing pollution from algae blooms or using water supply created by floods related to the rising sea level.

2.e. Recommendations for decision makers

As a main concluding finding of the project, the recommendations for decision-makers were intended for private and public decision-makers, with a view to allow informed decisions on algae as a potential feedstock for biofuels.

These recommendations were formulated under four dimensions:

1. National and international research development and demonstration incentives for rapid deployment;
2. Inclusion of algae and aquatic biomass based biofuels in European legislative text on renewable energy and biofuels (especially in the RED Directive and 10% biofuels mandate);
3. Start-up of CEN working group aimed at preparing draft European fuel standards for definition of CEN fuel standards for algae and aquatic biomass derived biofuels and for their inclusion (in blends) in conventional diesel (eventual addenda to CEN EN590 diesel);
4. REACH Registration of algae and aquatic biomass derived biofuels.

These recommendations build on the reports on the state of the art of algae biofuels, their overall sustainability assessment and the coordination with relevant research activities carried out outside the AquaFUELs Consortium. These recommendations summarise the operative conclusions of the AquaFUELs deliverables, comments from Consortium members and the Expert Group.

The contributions from the presentations and discussions at the AquaFUELs Roundtable, held on October 20th-21st, 2011 in Brussels, Belgium, also formed a significant input to these recommendations. The concise summary of the AquaFUELs Roundtable forms the Annex 1 to these recommendations. In order to ensure the greatest scientific credibility, this report was refined according to the discussions held during the AquaFUELs Final Conference, held on June 30th, 2011 in Brussels, Belgium and further circulated to the participants.

3. Organise the dialogue within the scientific and pre-industrial algae biofuels sector in Europe also structuring future co-operation in the longer term

The first result of the project ended up in the **creation of a network and joint communication platform of European flagship projects.** This was achieved via a mapping of on-going R&D project on algae and more specifically on algae-to-biofuels production pathways.
The work achieved a comprehensive mapping of both finalised and on-going projects in the field of algae biomass with a special regard to research and demonstration projects focusing on algae-to-biofuels production pathways (the projects have been selected and listed according to their relevance to the scope of our AquaFUELs project). Such mapping provides an overview of the actions involved in each project, providing also contact details and, when possible, describing the specific relevance of each action to AquaFUELs, highlighting potential links and synergies.
The overall aim achieved through this action is to build up a database of information about projects which became instrumental in structuring the algae community. The projects listed form a direct complement to the previous "*Report on Main Stakeholders*" (AquaFUELs deliverable 1.3) finalised during the first phase of the project. The list also adds up to the database of contacts of deliverable 1.3 and further improves the listing of the scientific stakeholders that has been taken over by the European Algae Biomass Association (EABA).

Building up an initial networking and co-ordination with past and present projects, **AquaFUELs managed to reduce the overlapping and/or the duplication of work among the various initiatives which have recently been launched or are being undertaken in the algae-to-biofuels production chain**.

This work was mainly performed by EBB and UNIFI. In a first time, the EBB team put together a first draft list of projects and initiatives potentially relevant to the objectives of AquaFUELs in order to allow for further contributions from the scientific experts in the consortium.
To this aim, all projects possibly related to algae and to biofuels from the CORDIS database, for which the search returned 218 hits, and from the Intelligent Energy Europe (IEE) database (32 projects found). Further to this work, EBB contacted the Intelligent Energy Europe officer in charge of liquid biofuels within the IEE team, Mr. Emilio Font de Mora, for additional suggestions for projects relevant to the activities of AquaFUELs. Similarly, EBB integrated the suggestion from Dr. Philippe Schild, AquaFUELs project officer from the FP7 team dealing with energy issues, to coordinate with EUROBIOREF, a project funded by the European Commission to promote integrated processing of biomass in bio-refineries.
A major input was also received through the AquaFUELs Roundtable, which allowed AquaFUELs to be in contact with representatives from the ALCHEMIS, BIOFAT, BIOGRACE, ALGADISK, ENERGETIC ALGAE, BIOWALK4BIOFUELS, Carbon Trust's Algae Biofuels Challenge, etc. The projects contacted in the context of the Roundtable organisation had been in most cases contacted during the questionnaire phase. However, many of them were also suggested by project partners at different points of the project. Even some very recently approved projects (BIOFAT) or holders of project proposals (Energetic Algae) have been in contact with AquaFUELs.

Another important instrument used in order to build up co-operation and structure common work was the preparation and signing of **Barter Agreements**. The aim of this work was to sign at least 20 Barters Agreements between AquaFUELs, EABA and a number of projects both funded by the EU and non-EU funded.

As reported in the deliverable, the coordinator contacted 18 EU funded projects, and 28 Non-EU funded project, and 2 platforms, for a total of 48 contacts.

The barter agreements signed at the end of the project were: 7 (Harvest, BAMMBO, MABFUEL, Albaqua, Seaweed Biorefinery, Alganol, and the Flemish Algae Platform). Three are in the final part of the signing procedure (NutraMara, MicroAqua and GIAVAP). The task was developed first of all by selecting the projects to contact for the signature of the barter agreement. Then the scientific coordinator of the selected projects were contacted to explain them the AquaFUELs project and EABA's role, and to ask for their interest in signing a BA with the project. Although the number of Barter agreements was lower than in the objective, it is important to underline that such agreements where developed at a later stage of the project in order to enable the EABA to co-sign the Barter agreements. This is a very important element since Barter agreements will continue to exist and to be enforced well after the end of the AquaFUELs project. The EABA is nowadays signing more Barter Agreements with other projects with which the first contact was undertaken under AquaFUELs actions.

In fact after a first contact or once the barter agreement was signed, the people belonging to the project were invited to take part at the AquaFUELs final conference, and in order to realise in practice the collaboration between the two projects and with the EABA, and the link of the project's websites were added in the AquaFUELs one.

Obviously the institutions/industrial partners involved in these projects were invited to join EABA, and to EABA meeting in November 2011.

The project also created a **report on services exchanged**. Most of the services consisted in the invitations to the meetings as external observers and as active part, such as during the Round Table, and the invitation to the Final Conference. Then, some measures were taken in order to reinforce the collaboration between the projects, such as the:

- The visibility for the project in the web platform,
- The projects were connected to the network.

Invitation to join the **European Algae Biomass Association (EABA)** were also encouraged in order to keep alive even after the timeline of AquaFUELs the collaborations between the projects even after the end of the project, and the results are quite important, as today 77 members are part of it.

Although it was not possible to sign a Barter Agreement with the BioGrace Project, they have included Prof. Mario Tredici, Scientific Coordinator of AquaFUELs and President of EABA, in their Internal Newsletter in order to provide information about the project developments.

Synergic Meetings were also organised when different representative of other projects in the field of algae production of biofuels were invited to the two most important AquaFUELs meetings: the Roundtable and the Final Conference. Such participation was an excellent opportunity for the AquaFUELs consortium to spread projects results and to collect feedback on them. Two of the projects that signed Barter Agreements with AquaFUELs were presented at the Final Conference (Seaweed Biorefinery and Albaqua) as well as the GIAVAP Project. The meetings represented an important moment of exchange with the external stakeholders and with the representative of the European Commission, who attended.

The **coordination of Research** was dedicated to promoting synergies among projects related to AquaFUELs. Consortium members were invited to present the AquaFUELs Project and the subsequent establishment of the European Algae Biomass Association (EABA) to the annual conference organised by the Algal Biomass Organisation (ABO). As an association representing the interests of the algae sector, including for biofuels use, the ABO had expressed support and willingness to cooperate with European algae stakeholders from a very early stage.

AquaFUELs offered participation to Dr. Laurenz Thomsen, Jacobs University, Germany, who is leading a major algae project with the Linde group. Dr. Thomsen participated in the Roundtable, presenting his work and actively participated in the discussions. AquaFUELs also coordinated with Prof. Guillermo Garcia-Reina, leading expert in the Green Desert project, which was presented at the AquaFUELs Roundtable. The AquaFUELs Roundtable also provided a significant input to the Coordination of Research thanks to the information received on the following projects: ALCHEMIS (2010-2012), Photosynthetic Cell Factories, Solar-H and Solar-H2, SUNBIOPATH, Sealand Sole, SUNLIGHT, CO2 fixation, Reactor design, Food and Nutrition Delta, AlgiCoat, Wetsus and AlgaePARC. EnAlgae (2011-2015), BioAlgaeSorb (2010-2013), GIAVAP (2011- 2014), BIOFAT, BIOMAP, MAMBO and ALGADISK.

The AquaFUELs final conference also saw the participation of many prominent researchers not associated with the project. Among the scientific input received was a comment by Prof. Niels-Henrik Norsker (Biotopic), Mr. Bernard Kudla (Eco-solution), Mr. Alessandro Flammini (FAO), Mr. Anselm Eisentraut (IEA) and last but not least Prof. Robin Shields (University of Swansea CSAR).

It was generally recognised that one of the risks for research in the field of algae was duplication of work due to overlapping research activities due to a lack of information and coordination of research. In addition, many of the internationally renowned researchers in the field of algae expressed their concern with the incorrect claims made about algae as a feedstock for biofuels and the resulting deceitful expectations created for market players, including downstream users. It was deemed essential that coordination of research is continued and strengthened and the great number of uncoordinated research activities could be improved if coordinated by a single entity.

It is important to note that many stakeholders wished to develop their cooperation with both AquaFUELs the European Algae Biomass Association, which led to a modified strategy for scientific cooperation. Following this development, barter agreements had been modified to reflect the continuity offered by EABA to AquaFUELs. AquaFUELs sought coordination with organisations active in the field of advanced biofuels, which are the natural industrial application of the research field covered by AquaFUELs. It should be stressed that the establishment and support to the development of the European Algae Biomass Association (EABA) forms a distinctive feature of the AquaFUELs project in comparison with other research projects. Indeed, the coordination of research and the structuring of the scientific community undertaken under AquaFUELs will be instrumental in providing potential members to the EABA Scientific Committee. **The European Algae Biomass Association (EABA), which is part of the outcome of the AquaFUELs project, is taking over most of the tasks carried out by AquaFUELs, including coordination of research**.

Potential impact, main dissemination activities and dissemination of results

The **AquaFUELs web page** (www.aquafuels.eu) was created during the first month of the project and presented during the kick-off meeting, on January 12th-13th, 2010, in the premises of the European Biodiesel Board, Brussels, Belgium.

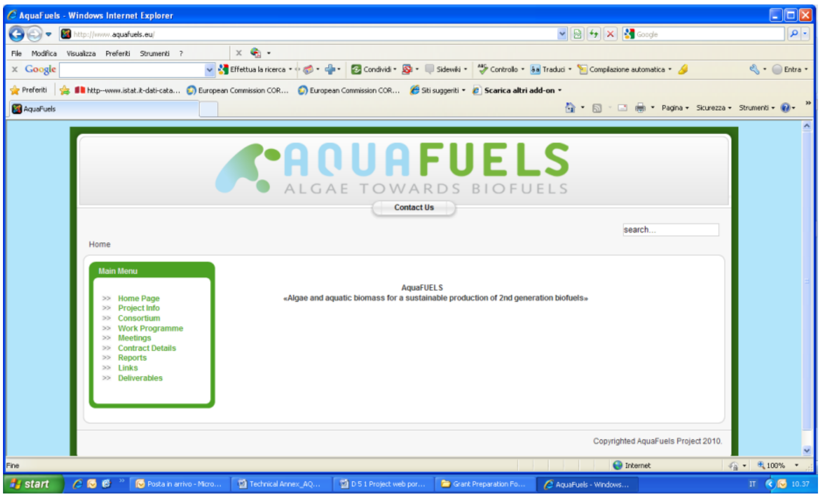


Figure 15: AquaFUELs web site – home page

The web portal was referenced in search engines of the web, including Acoon, ASR, Alexa, Amfibi, Amidalla, Bimeon, Boitho, Burf, ExactSeek, Google, Info Tiger, Myahint, ScrubTheWeb, Search Sight, Secret SELabs, SonicRun, Spiffy Search, Tower Search, Walhello and WhatUSeek. The web site has been structured as follows:

a PUBLIC AREA, including:

a. Home Page, with AquaFUELs and FP7 logo
b. Project Info, with the project abstract
c. Consortium
d. Work Programme
e. Meetings
f. Contract Details
g. Reports
h. Links
i. Deliverables

An INTRANET section was active as from the 3rd month of the project. A search pane and a contact section have been published in all sections, with a view to facilitate the website usability and the contacts with the project coordinator.

The results of AquaFUELs bear significance for researchers, industry and policy-makers, as a contribution to informed decisions on algae as a potential feedstock for biofuels. Therefore, the dissemination strategy intended for exploitation of the results has three dimensions:

5. National and international research development and demonstration incentives for rapid deployment;
6. Inclusion of algae and aquatic biomass based biofuels in European legislative text on renewable energy and biofuels (especially in the RED Directive and 10% biofuels mandate);
7. Start-up of CEN working group aimed at preparing draft European fuel standards for definition of CEN fuel standards for algae and aquatic biomass derived biofuels and for their inclusion (in blends) in conventional diesel (eventual addenda to CEN EN590 diesel).

This plan builds on the state of the art of algae biofuels, their overall sustainability assessment and the coordination with relevant research activities carried out outside the AquaFUELs Consortium. As such, this plan summarises the operative conclusions of the AquaFUELs deliverables, comments from Consortium members and the Expert Group. The report on research needs (deliverable 3.1) and the recommendations for decision-makers (deliverable 3.8) developed during the project proved to be useful stepping stones towards the final report, as they allowed to summarise and streamline the findings of the more academic deliverables. The discussions held at the AquaFUELs Roundtable (October 20th-21st, 2011) and the AquaFUELs Final Conference (June 30th, 2011) also formed a significant input.

1. Research, Development and Deployment

Technological bottlenecks could be found at all steps of the algae biofuels production pathway. The high costs of algae production could be decreased by scaling up and overcoming the bottleneck of harvesting, extraction and dewatering. However, increased productivity through improved biology and biotechnology could also balance the high costs of algae production. The identification of one specific pathway and strategic planning to address each of its bottlenecks are necessary to unlock the potential of algae for biofuels production.

One of the main findings of the project is that macro-algae for biogas or bioethanol production would show the greatest potential. Accordingly, future funding opportunities should take due account that macro-algae received considerably less funding than micro-algae for research towards biofuels production, despite their greater potential as a biofuels feedstock. In this respect, AquaFUELs members welcomed the reference to macro-algae in the recently published FP7-ENERGY-2012-1, which comprises a topic on *Biofuels from microalgae or macroalgae* (ENERGY.2012.3.2.1). The interaction of large scale algal cultivation on its immediate surrounding area should be assessed, both from the point of view of possible environmental contamination and concerning possible contamination from unwanted organisms decreasing productivity. This is particularly true for macro-algae, which has both the greatest potential for cultivation in seawater and could also be harvested from the wild, provided that harvesting takes place in a sustainable way. Several AquaFUELs partners have already expressed their interest for this call in the specific perspective of macro-algae.

Progress on the biology of algae could be achieved by sequencing and annotating algae strains of relevance to algae biofuels, including their relevant metabolic pathways, photosynthetic properties or ability to grow with a high growth rate to high biomass densities. The consortium identified 72 species. These strains reflect the parameters needed for an algae to be suitable for biofuels production: productivity, robustness, harvestability, an appropriate composition and easy accessibility of components, the possibility to valorise co-products and local origin. Prof. Tredici, AquaFUELs scientific coordinator, supports the publication of the findings achieved through the reports on biology, biotechnology and taxonomy in a scientific publication. To this aim, a single document merging these reports (*Merged report on Taxonomy, Biology and Biotechnology*) was submitted to the European Commission in addition to the deliverables due to be submitted under the project. In parallel, further projects on biology aspects will play an instrumental role to understand respectively the potential of genetically modified algae in cultivation. This project will be given exposure by the European Algae Biomass Association (EABA), which has expressed its interest in this project.

1.a. Technological feasibility

On the technological level, the biggest challenge for micro-algae remains scaling up production to the size of a commercial algal biofuel plant, as all parameters of algae cultivation represent a challenge when applied at a large scale. Mixing, gassing, water management, cleaning, logistics, control of cultivation parameters, etc are all challenges when deployed at a large scale. For macro-algae, the development of algae farms at sea represents the main technological bottleneck. Pilot plants reflecting the conditions of commercial production, including siting, could allow confirming the scaling-up potential of algae cultivation. Projects integrating the entire production chain to produce bioethanol and biodiesel from algae, will play an essential role in identifying possible solutions and potentially achieve the breakthroughs needed to advance towards commercial production.

1.b. Technological challenges

Harvesting, extraction and dewatering represent both a technological challenge and an energy-intensive step likely to hamper the economic viability and the greenhouse gas intensity of algae biofuels, making them a priority for further research. On the opposite, the price gap between open and closed systems has been reduced and further research in photobioreactor design would need to take due account of the existing research before engaging into further developments. Further technological breakthroughs are essential to improve the economic viability of algae biofuels, e.g. “milking” the algae to avoid the energy-intensive harvesting, extraction and dewatering. The currently low net energy ratio of algae cultivation should be improved, as it is the key factor to improve both the economic and environmental sustainability of algae biofuels. Neither economic sustainability nor environmental sustainability are optional, as the market for biofuels is driven by both prices and environmental benefits and because algae biofuels would be legally required to meet the mandatory sustainability criteria applicable to biofuels in the EU. Projects integrating the entire production chain to produce bioethanol and biodiesel from algae will contribute to advance towards technological feasibility due to the involvement of several advanced technology solutions, e.g. the harvesting and dewatering devices used in the pilot plant.

1.c. Fuel quality

Most studies on algae focus on the production of algae until extraction, while conversion into biofuels and the quality of the final biofuel have been less investigated. Fuel quality is a major parameter for the marketability of fuels and has an impact on biodiesel quality, since the characteristics of the initial feedstock affect the quality of the final biofuel. On the opposite, the conversion to biogas or bioethanol offers greater flexibility in terms of feedstock type. None of the presented pathways currently qualifies as a biofuel production process allowing the economically viable production of renewable fuels. Macro-algae conversion to biofuels appeared the most realistic perspective. Indeed, bioethanol and biogas productions are compatible with a wet feedstock and macro-algae are easy to harvest. Algae could follow the way opened by current biofuels, for which discussions on fuel quality in general and fuel standardisation work in particular started shortly before commercial availability of biofuels. Indeed, the European standardisation body CEN expressed interest to start work towards a Workshop Agreement – a workshop on the technical specifications of algae biofuels intended to take stock of the technology and market, representing a preliminary work to a possible technical standard.

1.d. Greenhouse gas savings

The project work on sustainability (WP3) stressed the need for European LCAs reflecting operations in largest pilot plants to replace the currently available LCAs. These LCAs would need to be based on the methology of the Renewable Energy Directive, including achieving 50% GHG savings compared to fossil fuels, because meeting the sustainability requirements would be a prerequisite to algae biofuels production. The need for LCAs taking into account the positive sustainability characteristics of algae was also stressed, e.g. the potential negative pressure on land, water and soil from algae cultivation and the extra protein produced. It was generally agreed that these discussions are not an immediate concern to algae biofuels, for which commercial production is still not a reality. However, the EU sustainability criteria for biofuels set out in Directive 2009/28/EC would require that algae biofuels achieve 60% greenhouse gas savings compared to fossil fuels to count as renewable energy in transport. In effect, this requirement means that algae biofuels sustainability is a prerequisite to marketability and will need to be addressed as soon as commercial production is considered. In this respect, the role played by EBB in the review of the default values for biofuels is promising and could pave the way for a favourable treatment of algae biofuels when commercial production becomes a reality.

1.e. Economic viability

Many uncertainties still remain on the economic viability of algae biofuels, for which costs are often hypothetical and reflecting future aspirations than practical experience. Despite the unreliable nature of the existing data, certain trends could be observed, such as the lower cost of open ponds compared to photobioreactors. Generally, it appears that very significant cost reductions would need to be achieved to allow algae to compete with other potential biofuels feedstocks. A 50% cost reduction can be obtained when using waste CO2 and nutrients, restricting the possible locations to areas where water eutrophication and industrial CO2 emissions are high. It would be desirable to develop data on the performance of large scale systems designed specifically to produce biofuels. For economic viability as well, further projects will play an essential role as it will lead to better understanding the economics of continuous (year-round) production of a large 10 hectares pilot plant and involve low-cost technologies.

1.f. Co-products valorisation

The general opinion that algae co-products are essential to the economic viability of algae biofuels is not matched with sufficient data. Algae production for biofuels needs to be integrated with other production pathway in a bio-refinery approach. In this respect, further steps towards the viability of algae biofuels could be the development of large algae production plants for value-added applications (food, feed, cosmetics), where the co-products would be valorised as biofuels. Moreover the treatment of waste effluents (liquids or gases) from other activities (population, industrial, agricultural) not only improved the economic feasibility of the biofuel production process but also enhances its sustainability. Generally, one of the findings of the project is the importance of developing parallel industrial applications for algae components which are not used for biofuels production and possibly of higher value, in line with the FAO recommendations in this respect. Therefore, it is expected that the work of the European Algae Biomass Association (EABA), pursuing all possible applications of algae including biofuels, will be instrumental in unlocking the potential of algae for food, feed, industrial applications and energy.

1.g. Macroalgae

Although a macro-algae industry has emerged as a result of successive demand shocks, production at large scale remains to be demonstrated in Europe and the development of macroalgae farms at sea represents the main technological bottleneck. Pilot plants reflecting the conditions of commercial production, including siting, could allow confirming the scaling-up potential of algae cultivation. However, the low development of the biogas industry in Europe and the wide array of feedstock available for bioethanol production decrease the likeliness of macro-algae biofuels to be picked up by market players. Appropriate incentives could help bridging the gap between the advance production techniques for macroalgae and these industries. Generally, future funding opportunities should take due account that macro-algae received considerably less funding than micro-algae for research towards biofuels production. In particular, more studies on lifecycle assessment of macroalgae. Important quantities of macro-algae landing on the coasts of Europe would make it appropriate to produce bio-methane, provided that they come in sufficient quantities. Only 2 pilot plants for macro-algae (*laminaria*) currently exist, to be connected to wind farms. *Laminaria*, containing 60%

fermentable sugars, is well suited to biogas and bioethanol production and a bio-refinery approach could allow valorising valuable co-products.

2. European legislation on biofuels

2.a. Renewable Energy Directive (2009/28/EC)

The Renewable Energy Directive 2009/28/EC sets a binding target for 10% renewable energy in transport. Member States have to implement National Action Plans detailing how they will progressively increase renewable energies in transport and finally meet the 10% target, which becomes binding on January 1st, 2020. After releasing their National Action Plan next June 30th, 2010, Member States needed to transpose the Renewable Energy Directive into national law by December 5th, 2010. However, the transposition process was still on-going in June 2011.

The Renewable Energy Directive made the targets for renewable energy in transport binding and set sustainability requirements increasing over time. The mandatory greenhouse gas savings are 35% compared to fossil fuels until January 1st, 2017, when 50% will be required. On January 1st, 2018, new plants commissioned after January 1st, 2017 will need to achieve 60% greenhouse gas savings. In addition, the EU is now contemplating further requirements on indirect land-use change. The increase in greenhouse gas emissions savings and the commercial availability of advanced biofuels is the ultimate objective of these requirements. EABA members are committed to reaching commercial availability for algae biofuels, but this goal will only be achieved if Member States grant the necessary support to R&D, in particular to initiatives aiming to reach commercial scale production.

2.b. Double-Counting

Double counting applies to biofuels produced based on raw materials allowing a diversification of biofuels feedstocks, which is the case for algae according to the Renewable Energy Directive. As already observed for other double-counting feedstocks, the higher price and demand for double-counting biofuels would be a strong incentive for the development of algae biofuels, which are still more costly to produce than biofuels currently on the market.

2.c. Greenhouse Gas Savings

Member States are free to define waste and residues, provided that they are not the intended product of a production process. Classifying all algae materials left after the extraction of certain substances could help valorising these materials as biofuels feedstock. This aspect is essential, because algae will only become economically viable if all algae materials can find a potential end market. As waste and residues automatically receive a zero life-cycle emission value, classifying algae after extraction as residues would allow producing advanced biofuels with high greenhouse gas savings.

2.d. Support to biofuels with additional environmental benefits

Member States can not only support both the research and development towards advanced biofuels, but also compensate the price difference between these biofuels and competing products. This support proved instrumental in creating the first biofuels market in the EU and the same actions must be introduced for algae biofuels. This is all the more relevant that algae biofuels have been estimated to be 10 times more expensive than the target price for commercial production.

2.e. Land use

The distinctive advantage of algae is their potential to provide an efficient and high quality feedstock with limited competition with food, feed or arable land surface. In the event that the European Union adopts legal requirements for biofuels regarding indirect land use change, the limited land use for the production of algae biofuels must be properly reflected.

2.f. Default value

A number of biofuels pathways have received conservative default values which can be used by producers not willing to assess specifically the greenhouse gas emissions from their fuels. In this respect, the inclusion of a default value for algae biofuels, once commercial production materialises, would be essential to allow a level-playing field with current biofuels.

2.g. Revision of the Energy Taxation Directive

Directive 2003/96 has been one of the major pieces of legislation for biofuels, because of the possibility for Member States to grant detaxation to biofuels. In the EU, taxation is decided by Member States, but the Energy Taxation Directive 2003/96 sets the framework for national taxation, e.g. minimum taxation levels, different taxation between end-uses, possibility to exempt certain energy products from taxation, etc.

The European Commission proposal to revise the Energy Taxation Directive has set taxation levels for fossil fuels, which would also apply to all fuels used to substitute them. It would be essential to maintain this fair approach in order to allow for algae biofuels, when they are commercialised, to have full legal certainty on the levels of taxation.

The proposal also exempts biofuels from the CO_2 tax and allows Member States to grant detaxation for biofuels until December 31st, 2022. Detaxation would be essential in the emergence of algae biofuels and it would be important that the final revision on the Energy Taxation Directive reflects the initial provisions on these aspects.

3. Standardisation

Algae biofuels, when technologically feasible, will need to fit into current markets and standardisation could allow their smooth introduction. Technical standards are widely accepted, making them de facto binding in many instances despite their voluntary nature. Standards improved confidence in new technologies from established industry players and more generally, clients.

During the standardisation work, experts from authorities, industry, consumer organisations and other stakeholders participated in the standardisation process, which is kept open and transparent and consensus-driven. European standards published by CEN officially supersede national standards, implying that national standards covering the same aspects have to be withdrawn.

There are currently technical standards on the quality of biofuels, as EN 14214 for biodiesel and EN15326 for bioethanol. In addition, biofuels are also covered by the standards for fossil fuels (EN 590 for biodiesel and EN228 for unleaded petrol), because biofuels are commercially available in a blends with fossil fuels. In addition, the interest shown by the aviation sector for algae fuels indicate that algae biofuels will also need to meet the specifications for jet fuel, which are chiefly set by the US standard ASTM D1655.

A CEN Workshop Agreement could help summarising the situation on the new market of algae biofuels, before proper standardisation work can be undertaken. CEN Workshop Agreements are agreed between stakeholders and often used by innovative industry sectors, as it had been the case for biofuels. Currently, CEN work towards a Workshop Agreement on "paraffinic diesel from synthesis or hydrotreatment" is going on to address the emerging market for hydro-treated vegetable oils. The standard for biodiesel released in 2003 had supported the important increase in production and sales in this emerging sector, which has now reached commercial scale.

It would be essential for the emergence of algae fuels to launch CEN work towards a Workshop Agreement.