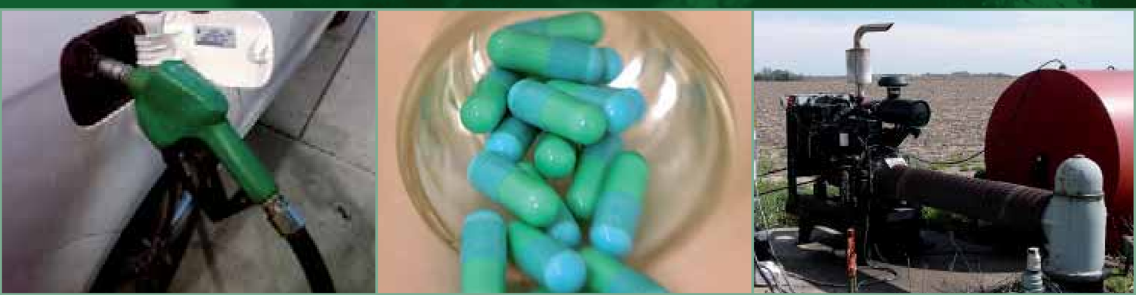
44

Algae-based Biofuels

Applications and Co-products



ENVIRONMENT AND NATURAL RESOURCES MANAGEMENT WORKING PAPER

ENVIRONMENT CLIMATE CHANGE [BIOENERGY] MONITORING AND ASSESSMENT

Background image in this page elaborated from “L’Encyclopédie Diderot et D’Alembert”

Other images from Right to Left: adapted from RobotSkirts; Sparktography; boutmuet; one30outerspace; zudark; siftnz; Audringje and
retrieved on flickr® on 29 July 2010 and released under a Common Creative Licence for adaptation, modification and building upon.

Copies of FAO publications can be requested from **Sales and Marketing Group - Communication Division**
Food and Agriculture Organization of the United Nations
Viale delle Terme di Caracalla - 00153 Rome, Italy

E-mail: **publications-sales@fao.org**
Fax: **(+39) 06 57053360**
Web site: **http://www.fao.org**

Environment and Natural Resources series design: studio@bartoleschi.com, 2004

FAO Aquatic Biofuels Working Group

Review paper

Algae-based biofuels: applications and co-products

July 2010

ISBN 978-92-5-106623-2

Acknowledgements

The development of this review paper was recommended in December 2009 by the Interdepartmental Working Group on Bioenergy with the objective of reviewing the potential of integrated production of fuel, food, feed and other valuable chemicals from algae. This would provide information on the potential benefits in developing countries in order to promote the exchange of knowledge, experiences, and, more broadly RD&D in this field. This work was coordinated by Alessandro Flammini (GBEP Secretariat) under the overall guidance of Olivier Dubois (FAO).

The authors of this paper are Sjors van Iersel and Alessandro Flammini.

We would like to acknowledge the valuable contributions of Pierpaolo Cazzolla (IEA), Joel Cuello (University of Arizona), Susanne Hunt (HuntGreen LLC), Cristina Miceli (University of Camerino), Jim Sears (Algal Biomass Organization), Emanuele Taibi (UNIDO), Mario Tredici (University of Florence), Jinke van Dam (SQ Consult Associate) and other FAO colleagues, who provided valuable inputs and support in reviewing this paper.

The information contained does not necessarily reflect the official views of the FAO.

This review paper provides a joint contribution to the programme of work of the FAO Interdepartmental Working Group on Bioenergy and the Global Bioenergy Partnership (GBEP).

www.fao.org/bioenergy/aquaticbiofuels

GBEP Global Bioenergy Partnership

Executive summary

Although the need for dense energy carriers for the aviation industry and other uses is assured in the foreseeable future, there is currently lack of viable renewable alternatives to biofuels for that component of the transport sector. Algal biofuels have many advantageous characteristics that would lower impacts on environmental degradation in comparison to biofuel feedstock and in some cases improve the well-being of developing and developed communities.

Within the international debate surrounding algal biofuels, there are both endorsement and scepticism coming from scientists with different views on the ability of this source of biofuels to meet a significant portion of fuel demand. The private sector has invested in the technology to grow algae and convert it to liquid biofuels over the last few years. Technical scientists and business people tend to focus on their specific perspective rather than on a global perspective that clearly analyses the benefits (or drawbacks) of a technology for sustainable development. Sustainability experts need to liaise with different stakeholders to assess the practical applicability of algal biofuels and their suitability for developing regions in order to provide governments and policy-makers with the appropriate information to formulate optimal solutions.

Algae have a number of characteristics that allow for production concepts which are significantly more sustainable than their alternatives. These include high biomass productivity; an almost 100% fertilizers use efficiency, the possibility of utilizing marginal, infertile land, salt water, waste streams as nutrient supply and combustion gas as CO_2 source to generate a wide range of fuel and non-fuel products. Furthermore, another competitive advantage of algal biofuels is that their development can make use of current fossil fuel infrastructures. As more expensive sources of fossil fuels are starting to be exploited at the expense of the environment, the more rapidly algal biofuels can provide a viable alternative, the more rapidly fossil fuel consumption will be reduced.

Possible algal biofuels include biodiesel, bioethanol, bio-oils, biogas, biohydrogen and bioelectricity, while important non-fuel options include the protein part of algae as staple food, certain algal oils, pigments and other bioactive compounds as health foods, neutraceuticals or pharmaceuticals, or other renewable inputs for the food industry, including as feed for livestock and aquaculture. In addition, non-food compounds can be extracted for use by the chemical industry, in cosmetics and skin care products, as organic fertilizers and as an alternative fiber source for the paper industry.

Algae advantages and drawbacks should be considered without excessive enthusiasm of prejudices but exclusively with a scientific approach.

At the time of this publication, large scale production of algae-based biofuel is not yet economically viable enough to displace petroleum-based fuels or compete with other renewable energy technologies such as wind, thermal solar, geothermal and other forms of bioenergy. Current production efficiencies for algal biomass production result in a cost range of USD 0.60/kg to USD 7/kg. As shown in the report, the approximate cost of algal biodiesel is even higher (usually more than USD 6/liter) primarily dependent on the quality of the final product and the external conditions.

However, with policy support and incentives, the algal biofuel industry will continue to develop and, assuming that this technology will follow cost trends of other renewable energies, costs will decrease to eventually compete economically with fossil fuels. It is clear that the technology embodies some desirable characteristics for the environment and society, yet one of the principal challenges is the economic viability of this technology. Supportive policy conducive to advancement in research, development and deployment of algal biofuels could eventually contribute to the alleviation of a number of energy, hence environmental, problems.

Despite their high potential, both in terms of productivity[1] and sustainability, most algae-based biofuel (ABB) concepts still require significant investments to become commercially viable. One technical solution that would speed viability and sustainability, hence the competitiveness of ABB, is the co-production of multiple products to generate additional revenue.

The non-fuel co-product options investigated in this review can technically be co-produced with at least some of the ABB options (usually in the form of health food), except if complete algal biomass is the end product. From an economics perspective, there are many algal products with high market value, but their market volume is incompatible with the market volume of biofuels, preventing large scale use of the same co-production concept. More market compatible products are fertilizers, inputs for the chemical industry and alternative paper fiber sources. However, these have a market value that is similar or a slightly higher than biofuels. While a continued rise in fossil oil price can be expected, the production costs of algae are projected to drop as the technology develops and experience increases.

[1] Microalgae biomass productivities of 80 tons per hectare per year, which are in the range of high yields attained with C4 crops (e.g. sugarcane) in the tropics, must be considered as the maximum achievable at large scale (Tredici 2010).

Commercial production and harvesting of natural populations of both microalgae and seaweed predominantly take place in developing countries, indicating available experience, good environmental and economical conditions like sunshine and low labour costs. Large-scale industrial applications require a large amount of marginal, cheap but often ecologically valuable land and water sources. For poor rural communities, well designed small-scale Integrated Food and Energy System (IFES) approaches are most suitable, potentially reducing ecological impact while providing fuel, animal feed, human protein supplements, wastewater treatment, fertilizer and possibly more products that generate additional income. Capital inputs have to be minimized for this group, which means that the cultivation system would most likely be the open raceway pond, constructed in an area with an easily accessible, sustainable water supply, or *in situ* collection of macroalgae.

Novel technologies are contributing to develop a whole range of novel foodstuffs and renewable non-food commodities from algae in a sustainable way.

Capital input, immature technology, knowledge required for construction, operation and maintenance and the need for quality control are significant barriers to algae-based systems (and IFES concepts in particular). Although productivity and sustainability are potentially much higher for integrated systems, the time and effort needed to create a viable algae-based IFES concept seems to be significantly higher than for IFES concepts based on agriculture.

The report shows that, while the technology for large scale algal biofuel production is not yet commercially viable, algal production systems may eventually contribute to rural development, not only through their multiple environmental benefits but also through their contribution of diversification to integrated systems by efficiently co-producing energy with valuable nutrients, animal feed, fertilizers, biofuels and other products that can be customized on the basis of the local needs.

Algae-based biofuels: applications and co-products
by Sjors van Iersel and Alessandro Flammini

117 pages, 7 figures, 10 tables

FAO Environmental and Natural Resources Service Series, No. 44 – FAO, Rome 2010

The list of documents published in the above series and other information can be found at the website:
www.fao.org/nr

Table of Contents

1 Introduction

The FAO Inter-Departmental Working Group (IDWG) on Bioenergy established the Aquatic Biofuels Working Group (ABWG) in 2008 as an exploratory initiative with the aim of assisting interested stakeholders to understand the potential and sustainability of biofuel production from algae and fish waste in order to exchange knowledge and experiences with the objective of promoting R&D in this field. The focus of the ABWG activity is on the developing country context and the feasibility of pursuing biofuel production from algae and fish waste. As a first step, the report “Algae-Based Biofuels - A Review of Challenges and Opportunities for Developing Countries” has been published in 2009; which allowed FAO and interested stakeholders to better understand the potential and impacts of different technology options for algae-based biofuels production in developing countries[2].

The importance of investigating new options offered by algae cultivation is motivated by the fact that algae are very efficient at converting light, water and carbon dioxide (CO_2) into biomass in a system that does not necessarily require agricultural land. Depending on the concept, the water can be salty and the nutrients can come from waste streams. Depending on the species and cultivation conditions, algae can contain extremely high percentages of lipids or carbohydrates that are easily converted into a whole range of biofuels including biodiesel or bioethanol. Furthermore, the remaining biomass, mostly protein and carbohydrate, may be processed into many other products such as: foods, chemicals, medicines, vaccines, minerals, animal feed, fertilizers, pigments, salad dressings, ice cream, puddings, laxatives and skin creams (Edwards 2008). Algae- based products can serve as an alternative to a wide range of products that are currently produced from fossil resources or land-based agriculture, but without requiring high quality land and in some cases without requiring fresh water[3], with CO_2 as the only carbon input.

Some key conclusions of the first review paper are that the most significant obstacles are the high production costs and the fact that algae-based biofuels initiatives (typically R&D) are still predominantly based in developed countries. Both these conclusions justify a broadening of the scope to include the co-production of fuel, food and other valuable co-products. This co-production is seen as an important option to break though

[2] This review paper can be found online at http://www.fao.org/bioenergy/aquaticbiofuels/abwg-activities

[3] The fresh water need could become consistent for open ponds applications due to water evaporation

the barrier of economic viability, while at the same time producing a new protein source for human, livestock and fish consumption; the high nutritional value of algal protein has actually been known for decades, while malnutrition is one of the most serious problems in developing countries.

As a follow-up to the work previously undertaken by the ABWG and the consequent publication of the review paper, this document provides an overview of practical options available for co-production from algae and their viability and suitability for developing countries.

In the last few years, hundreds of scientific papers have been published on the use of algae in producing a wide variety of products and, at the same time, several companies have been set up in this field with the aim of entering the market. Therefore the focus of this review is on using light and CO_2 as the main energy and carbon sources for the biomass production of non-plant organisms (i.e. algae) for multiple purposes through integrated systems. In particular *integrated food and energy systems* (IFES) that rely on algae will be discussed and the wide range of algae-derived products will be briefly overviewed. These systems aim at the simultaneous production of food and energy through sustainable land use management, contributing to meet higher living standards, through the production of energy, food, feed, bio-chemicals and fertilizers. Integrated systems ensure a more sustainable management of land and natural resources by combining the production of bioenergy and other valuable co-products by transforming the by-products of one production system into the feedstock for another, hence intensifying the overall production on the same land and contributing to alleviate pressure on natural resources. Given the nature of algal application and their reduced need for land, algae can potentially optimize land use to meet multiple human needs.

Algae are defined as eukaryotic macroalgae and microalgae, but also prokaryotic autotrophic species such as cyanobacteria. These groups contain species that can make use of organic carbon, e.g., glucose, as a carbon source (often yielding higher productivities and biomass concentrations), but as this would require separate feedstock production (instead of CO_2 utilisation) there is a subsequent loss of many sustainability benefits. This option, known as heterotrophic cultivation, will not be considered in this report. While macroalgae are usually cultivated in their natural habitat, microalgae can be cultivated in dedicated cultivation systems, allowing for better manipulation of the growth conditions and subsequent quality control. The latter is a requirement for most algal product applications; therefore this report focuses primarily on microalgae.