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# “Algae and Environmental Sustainability”

**Edited by Bhaskar Singh and Kuldeep Bauddh (Central University of Jharkhand, India) and Faizal Bux (Durban University of Technology, South Africa), Developments in Applied Phycology, Volume 7, Springer India, New Delhi, India, 2015, 181 pages, ISBN: 978-81-322-2639-0, £72.50, US$119.00, €104.33**

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## Introduction

“Algae and Environmental Sustainability” is a compilation of 14 chapters contributed by different authors and collected by Singh and Bauddh (Central University of Jharkhand, India) and Bux (Durban University of Technology, South Africa). It is the seventh book in the Developments in Applied Phycology series from Springer. The chapters can stand alone, and together they cover most points of intersection between algae and the environment. Several chapters focus on some aspect of using algae to treat contaminated streams (for example biosorption and phycoremediation) and one deals with remote sensing of harmful algal blooms, but most of the chapters touch on sustainability in some way.

## Overview

Chapter 1, by B. Bharathiraja (Vel Tech High Tech Dr. Rangarajan Dr. Sakunthala Engineering College, India) *et al.*, introduces the cultivation of micro- and macroalgae and their potential as feedstocks for producing renewable biofuels. Algae are promising biofuel feedstocks because they have high photosynthetic efficiency, accumulate large amounts of lipids, can be cultivated on non-arable lands, recycle atmospheric carbon dioxide and can use waste effluents as nutrient sources. The authors describe both photobioreactors (PBRs) and open raceway ponds. PBRs allow for complete control over growth parameters while open raceway ponds are less expensive. Next, the authors review products of economic value derived from microalgae. These include triglycerides, which can be transformed into biodiesel *via* transesterification, and sugars, which may undergo fermentation to produce alcohols. Other coproducts noted include pigments, active pharmaceutical ingredients and proteins. The authors argue that the economic viability of commercial biofuel production from algae will depend on the ability to integrate recycled nutrient waste effluents, mitigate atmospheric greenhouse gases, and minimise process waste streams by producing valuable non-biofuel coproducts. Overall this chapter provides a suitable introduction to points of intersection between environmental sustainability and algae.

In Chapter 2, Sonal Dixit and D. P. Singh (Babasaheb Bhimrao Ambedkar University, India) present the capabilities of algae to remediate wastewater streams charged with organic and heavy metal pollutants. Through the process of phycoremediation, algae remove pollutants from wastewater passively with surface adsorption *via* interactions between their cell wall constituents (such as polysaccharides and proteins) and pollutants. The pollutants are then subsequently absorbed into the algal cells. The authors show that certain algae species have higher capacities than chemical sorbents and are also capable of simultaneously removing multiple pollutants. After describing the effects of operating conditions (such as pH, contact time, temperature and concentrations of metals and algae) on biosorption of heavy metals, Sonal and Singh present other applications of bio-coproducts extracted from algae, which include uses as food and feed, fine chemicals, pharmaceuticals and fertilisers.

Chapter 3, by Maureen Kesaano (Utah State University, USA) *et al.*, focuses on the application of attached algal growth systems, known as 'biofilms', for remediating wastewater streams. Algal biofilms are immobilised to surfaces, which simplifies their recovery in comparison to algal cultures freely suspended in water. The authors indicate that the realisation of algal-based biorefineries will depend on the availability of inexpensive fertilisers and that these can be obtained through the remediation of wastewater by algal biofilms. Suitability of a given algal biofilm for treating wastewater depends on the nutrient profile within the wastewater and the capability of the biofilm in purifying the water to meet required reclamation standards. Factors affecting the algal strain selections for biofilms will therefore depend on the nutrients available within a waste stream, geographical location, temperature, light and pH. The authors discuss mathematical modelling of algal biofilm growth and their applications for determining conditions to maximise biofilm cultivation and purification of wastewater. Overall, this chapter provides a thorough introduction to the remediation of wastewater streams by algal biofilms and the production of bioproducts (**Figure 1**).

Chapter 4, by T. V. Ramachandra (Indian Institute of Science, India) *et al.*, is an overview of several studies focusing on algal treatment of urban wastewater. The studies focus on remediation of waste originating from the urban epicenters of Bangalore and Mysore in India. The treatment facilities include man-made lakes, mechanical treatment systems and facultative pond-based systems. The authors document the capabilities of algal monocultures and consortia, mixtures of euglenoids and members of Chlorophyceae, in improving the water quality while also quantifying the accumulation of algal lipids suitable as biofuel precursors. Economic and sustainability analyses and an evaluation of the community acceptance on the three treatment facilities are also provided. This chapter provides a detailed, holistic overview on the industrial-scale development of algal-based wastewater remediation plants that in turn can produce precursors for biofuels.

Chapter 5, by J. L. Ramous-Suárez (Procycla SL, Spain) *et al.*, is a comprehensive review of anaerobic digestion and its application in algal biorefineries. The authors propose that after value-added products are extracted from the cultivated algae, residual organic matter could undergo anaerobic digestion to produce biogas and digestate, which could be recycled for further algal cultivation. The $CO_2$ in the biogas may serve as a carbon source while the digestate contains

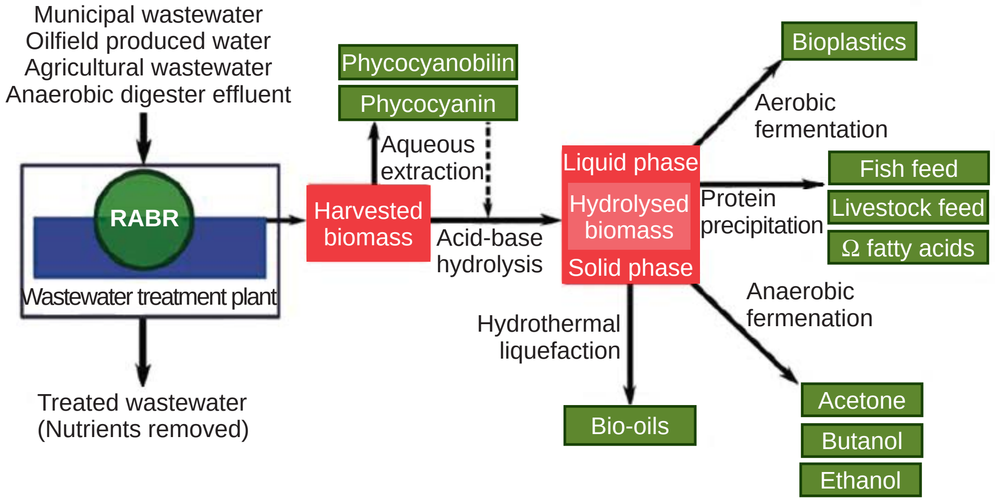



Fig. 1. Coupling wastewater treatment with algae production (Reproduced by permission of Springer India)

nitrogen- and phosphorus-containing compounds. The authors provide further insight on the influence of operating conditions on anaerobic digestion and the use of thermal, biological and physical pretreatments to biomass that may improve their digestibility. Chapter 5 elucidates a process that may contribute to the profitability of algal biorefineries by closing the large nutrient gap needed for cultivating biomass.

Chapter 6 is devoted to evaluating algal-biomass-based biohydrogen production from laboratory-scale to commercialisation. Richa Kothari (Babasaheb Bhimrao Ambedkar University) *et al*. elaborate on biohydrogen production *via* biophotolysis (BP) and dark fermentation (DF) and discuss factors such as pH, temperature and immobilisation. Additionally, the biomass production suitability of various types of photobioreactors is profiled. However, modest information is available regarding the influence of bioreactor types on the BP and DF bioprocess routes. Finally, economic factors, feasibilities and major bottlenecks in algae-based bioprocess routes are also discussed, demonstrating that biohydrogen production by algae is a promising alternative energy source.

Microalgal biofuels primarily include bio-oil and biodiesel, which have utility in internal combustion engines in the transportation sector. Chapter 7, by Dipesh Kumar (Central University of Jharkhand) *et al*., focuses on the physicochemical characteristics and molecular constituents of bio-oil and biodiesel. It gives insight into the advantages and limitations of characterisation techniques for determining lipid content and profiles in microalgal oil, such as Nile red fluorescence, pulse amplitude modulated fluorometry, nuclear magnetic resonance (NMR), gas chromatography-mass spectrometry (GC-MS) and Fourier transform infrared (FTIR) spectroscopy. The selection of a particular method is subjective and depends on several factors as indicated by Kumar *et al*.

Chapter 8, by Poulomi Chakravarty (Central University of Jharkhand) *et al.*, illustrates the application of algal biosorption to treat waste streams in the dye industry. The authors show the potential for marine and fresh water algae as suitable biosorbents because of cost-effectiveness, high efficiency and selectivity. The information provided will prove useful for those who work on eliminating dyes from aqueous solutions. The authors conclude that algae could be viable at the community level for ecofriendly dye contamination removal.

Chapter 9, by Sushil Kumar Shukla (Central University of Jharkhand) and Pradeep Kumar Mishra (Indian Institute of Technology (BHU), India), mainly emphasises developing an effective waste treatment plan for distilleries based on coagulation followed by mixed culture (fungal and algal) aerobic treatment. The prominent environmental concerns from the distillery industry are the spent wash and large quantities of wastewater. Details regarding a bioremediation and decolourisation case study are provided for a Lords Distillery in India. The facility uses an integrated approach combining coagulation and aerobic degradation for removal of the contaminants from anaerobically biodigested distillery effluent. The authors conclude that microalgae in an aerobic degradation process along with fungi seems to be a potentially cost-effective and environmentally friendly treatment process.

Triacylglycerols are storage lipids in microalgae that are prime candidates for biofuel production. Chapter 10, by Sheena Kumari (Durban University of Technology, South Africa) *et al*., focuses on application of genetic engineering to enhance lipid production. A brief overview of lipid and fatty acid biosynthesis pathways in microalgae is also provided in the chapter (**Figure 2**). Given current biotechnology advancements, genetic engineering of microalgae offers an efficient method of strain improvement. Detailed information about challenges is also provided in forward and reverse genetics, for example the screening process, possibility of low or no expression and suitability for large-scale cultivation.

Chapter 11, by Sanjay Kumar Gupta (Durban University of Technology) *et al*., focuses on the use of algae and cyanobacteria for removing or degrading contaminants of emerging concern (CECs) from the environment. These compounds include, for example, pesticides, pharmaceutical and personal care products and detergents. Many of these CECs have been in long use, but analytical techniques have improved to the point where they can now be detected in environmental samples. The chapter provides convenient summaries of the research that has been done using photosynthetic microorganisms for bioremediation or biotransformation of different classes of CECs. These tables will be of interest to those working in this field and they give a nice overview for the casual reader. The authors conclude that phycoremediation shows promise, but that mechanistic understanding and exploration of microbial consortia is lagging behind.

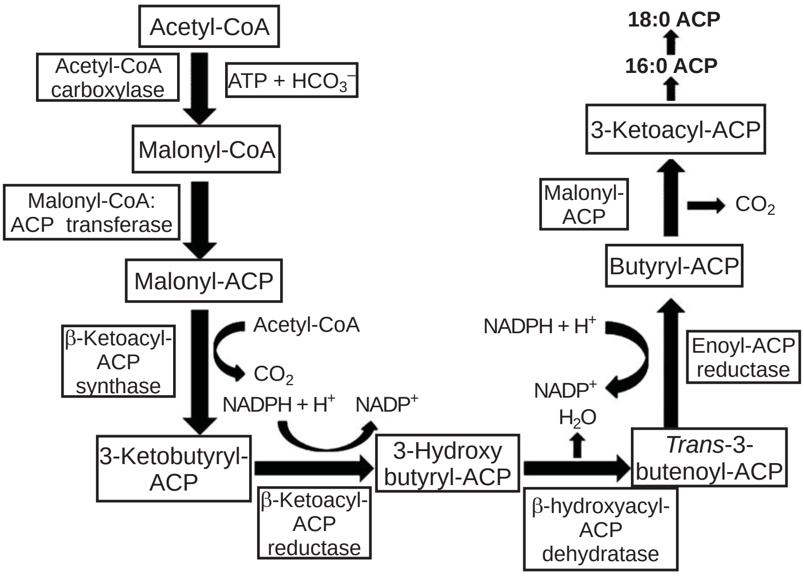
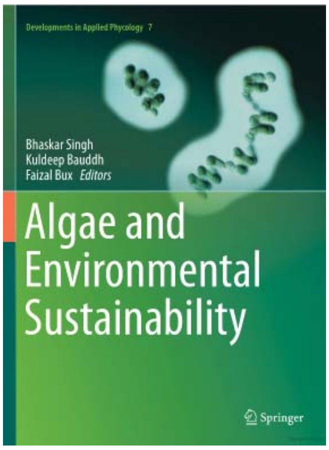



Fig. 2. Fatty acid biosynthesis pathways (Reproduced by permission of Springer India)

Abhishek Guldhe (Durban University of Technology) *et al*. contribute Chapter 12 on $CO_2$ sequestration by microalgae as a means of controlling $CO_2$ emissions from flue gas. The chapter gives a brief overview of competing $CO_2$ removal technologies (amine scrubbing and adsorption) and the relative advantages of biological $CO_2$ fixation. It proceeds to discuss the chemistry of photosynthesis and carbon fixation, good algae strains for $CO_2$ removal and the relative merits of raceway ponds and photobioreactors. There is a good summary of the influence of high $CO_2$ concentrations on algae growth. In some cases, high $CO_2$ concentrations lead to high cell densities, but in other cases it can also lead to acidification that hampers growth. The authors note the slow transfer rate of $CO_2$ from the gas to the liquid phase as a major bottleneck.

Chapter 13 provides a brief overview of the use of remote sensing technology for monitoring harmful algal blooms (HABs). Laxmi Kant Sharma (Central University of Jharkhand) *et al*. discuss the origin of HABs (such as discharges of nitrogen and phosphorus into water bodies) and environmental problems they create (such as toxicity and water quality deterioration). Such blooms often span an area of sufficient size that they can be observed and monitored remotely *via* satellite imagery, based on the colour, reflectivity and absorption properties of the algae pigments. This chapter includes a nice summary of the challenges and limitations associated with remote sensing of HABs.

The final topic in the book, life cycle assessment (LCA) of algae based biofuels, is appropriately placed at the end of the book as Chapter 14, by Dipesh Kumar *et al*. LCA examines the material and energy inputs for a process and then assesses the accompanying environmental impacts. LCA can be used, for example, to determine the extent to which an algal biofuel production process is net energy positive and reduces $CO_2$ emissions relative to fossil or competing biofuels. This chapter gives a broad overview and then highlights a few algae biorefinery LCA studies from 2011 or earlier. These focus on lipid extraction and biodiesel production rather than the more current technologies of hydrothermal processing of the whole biomass. Even so, the reader gets a basic introduction to LCA and a few of its early applications to algae biofuels.

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## Conclusion

This book provides a very accessible introduction and high-level overview of the various points of intersection between microalgae and the environment. These points include both remediation and sustainability considerations. The book could be useful initial background material for someone new to microalgae and the related uses and technologies. It can also provide a broadening experience for those who work more narrowly on one specific point of intersection between algae and the environment.

## The Reviewers

James D. Sheehan is a PhD candidate in the Department of Chemical Engineering at the Pennsylvania State University, USA. He is advised by Phillip E. Savage and his research focuses on modelling algae liquefaction kinetics, understanding the hydrothermal chemistry of proteins and recovering nutrient coproducts from hydrothermal processing.

Jimeng Jiang is a PhD candidate in Chemical Engineering at the Pennsylvania State University. She is advised by Savage and is developing processes for demetallation of biocrude from hydrothermal liquefaction of algae.

Phillip E. Savage is the Department Head for Chemical Engineering at the Pennsylvania State University. His laboratory is engaged in research on algae biofuel production *via* hydrothermal treatments and aspects related to environmental sustainability and ecology.

Currently algae are used for a relatively small number of industrial applications. Recent works have described in details the transition of the focus from algal-based bioenergy to high-value bioproducts, and the model of algae-based biorefineries (Laurens et al., 2017). In this review, we describe how recent landmark achievements have demonstrated the untapped commercial potential of algae-based applications. Algae (Macro/Microalgae): Its Impact on Ruminant Nutrition and Environmental Sustainability. Submit to Animals Review for Animals Edit a Special Issue. Journal Menu.Â  It is crucial, therefore, to find strategies to improve feed efficiency and decrease emissions. One approach is the use of algae in ruminant nutrition, which could contribute to the freeing up of land to grow crops for direct consumption by the human populace and lead to a concomitant increase in food security. Microalgae are a great source of PUFA (DHA, DPA, and omega-3), while brown seaweed (macroalgae) containing phlorotannins has the potential to optimise protein use efficiency, reduce environmental impact, and improve animal health and food quality. Algae and Environmental Sustainability" is a compilation of 14 chapters contributed by different authors and collected by Singh and Bauddh (Central University of Jharkhand, India) and Bux (Durban University of Technology, South Africa). It is the seventh book in the Developments in Applied Phycology series from Springer. The chapters can stand alone, and together they cover most points of intersection between algae and the environment. Several chapters focus on some aspect of using algae to treat contaminated streams (for example biosorption and phycoremediation) and one deals with remote