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"Advances in Biofuel Production: Algae and Aquatic Plants"

Edited by Barnabas Gikonyo (The State University of New York (SUNY) Geneseo, New York, USA), Apple Academic Press, Inc, New Jersey, USA, 2014, 398 pages, ISBN: 978-1-926895-95-6, £95.00, US$149.95

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Introduction

"Advances in Biofuel Production: Algae and Aquatic Plants" is a compilation of papers that have previously been published elsewhere, presented as 12 chapters. These have been edited by Barnabas Gikonyo, whose research interests range from the application of biocompatible polymeric materials for the repair of spinal cord injuries to the development of non-food biofuels. The book is intended to provide an overview and evaluation of the current status and prospects for fuel production *via* algae, microalgae and aquatic plants. As such, the book should appeal to general researchers with an interest in this area, rather than just specialists working in the field.

The book is divided into three main sections. Part One provides an overview of the current status and challenges in producing sustainable fuels from algae. Part Two, which consists of seven chapters and makes up the bulk of the book, examines both the supply potential and some of the current technologies relevant to biofuel production. The final section comprises three chapters dealing with next generation research, with a focus on progress in genetic developments. The chapters vary from those presenting more general aspects of biofuel production from algae to reviews of specific technological aspects (for example electromagnetic biostimulation of living cultures; use of anion exchange resins; next generation sequence systems). A single chapter deals with the catalytic transformation of biomass-derived acids into advanced biofuels.

Current Status and Challenges

The two chapters in Part One, which provides perspectives on the challenges facing scale-up and economics, will be of interest to general readers. Chapter 2 provides quantification of a number of the challenges, in particular those related to process economics, energy consumption and environmental acceptability. Using a variety of published data and life cycle analysis (LCA) studies, the authors, Douglas Aitken and Blanca Antizar-Ladislao (University of Edinburgh, UK), review the current state of knowledge and technology readiness of algal biomass to fuels. Their analysis covers a range of key aspects: choice of algal species and species control; reactor technology for growing algae; harvesting and separation technologies; water usage; product (fuel) types; and the use and impact of fertilisers. The authors highlight a number of barriers that will need to be overcome if commercial algal biofuel production is to be realised. Significant amongst these are energy consumption in the production process, for example to effect separation of the algal products from the aqueous medium; the use of fertilisers to deliver algae growth; and water

requirements. Interestingly, most algal biofuels are stated as likely to be net contributors to greenhouse gas emissions, mainly due to the current energy inputs required for algal biofuel production. The development of enhanced, low-energy separation processes and the use of waste water or recovery of nutrients are highlighted as areas for further research. The authors also propose that improved energy recovery from the available (non-oil) biomass will require the use of anaerobic digestion or combustion, even to the extent that it may be beneficial to ignore biodiesel and to simply recover energy directly using these two methods.

Biofuel for Today

Chapter 3, by Stijn Cornelissen (ZinInZin, Utrecht, The Netherlands), Michèle Koper (Ecofys bv, The Netherlands) and Yvonne Y. Deng (Ecofys UK), delivers a more positive perspective on the potential of algae routes to fuels. The authors take a similar broad overview of the role of bioenergy in a fully sustainable global energy system and present a model in which 95% of our energy needs are met by renewable energy, without a major reduction in activity levels, by 2050. Their analysis covers issues such as land use, food security, water requirements and greenhouse gas emissions and considers a wide range of renewable energy types. Recognising that significant development is still required for commercial production of biofuel from algal oil, the authors only include this as a technology option from 2030 onwards, from which point they allow algal oil to supply any remaining demands in oil routes after the use of residues, waste and bioenergy crops. Inherent in their model is the recycle of the non-oil components of algal biomass to provide nutrients and energy input into the growth and processing of the algae. They conclude that the amount of algal oil needed (equivalent to 21×10^{18} J of energy) and associated land requirements (3×10^5 km^2 of non-arable land) lie comfortably within the potential available and will result in a net reduction in greenhouse gas emissions.

Firoz Alam (Royal Melbourne Institute of Technology (RMIT) University, Australia) *et al*. in Chapter 4 provide further thoughts about the viability of algae routes to biofuel. While lacking the quantification of some of the earlier chapters, this short article concludes that microalgae offer immense potential for biofuel production. However, the authors re-emphasise a number of technical issues discussed in earlier chapters. In particular, they highlight the need for developments to reduce the huge energy losses (most of which is associated with extracting lipids) and to recover value from the majority (approximately 70%) of the biomass that is currently wasted, for example by the re-use of nutrients.

The theme of assessing the potential of algal biofuel production is further explored by Colin M. Beal (The University of Texas at Austin, USA) *et al.* in the next chapter, which focuses on two key criteria for success: the energy return on investment (EROI) and the financial return on investment (FROI). The analysis presented includes both direct (for example electricity usage in the process) and indirect (for example energy embedded in consumed materials) energy and operating costs. Results are presented for two scenarios: the experimental case (based on small scale lab data) and the highly productive case, a system with a greater biomass productivity (40× increase) and higher lipid fraction in the biomass (15× increase), as well as improved energy efficiency and re-use of 95% of cultivation water. These assumptions are described as optimistic but not unreasonable. As might be expected, the EROI for the highly productive case was significantly better than that of the experimental case, but still fell well short of that required to give a process that is competitive with conventional fuels. A similar result was reached for the return on investment criterion. Based on this analysis, the authors conclude that, even for the optimistic highly productive case, current technology falls well short of providing a route to fuels that can offer a profitable alternative to conventional energy sources. In addition, algal biofuel routes are stated to be more water intensive and resource intensive than conventional fuels. A number of technology limitations are identified by the model that will not be addressed by improving algal biomass productivity. For example, stoichiometry demands an increased nutrient requirement (with an increase in the associated energy embedded in fertilisers) with increased growth rates. On a more positive note, the model is used by the authors to generate a number of targets for research stakeholders to direct the development of commercially viable technology. These include the use of waste and recycled nutrients; the use of waste heat and flue gas as inputs to the process; development of energy efficient harvesting and separation methods; and development of ultra-productive algal strains. While the overall conclusion of this piece of work could be seen as highly negative

for algal fuels, the authors finish by stating that algae represent one of the few alternative feedstocks capable of producing fuel substitutes directly. 'Game-changing' biotechnology advances (for example the development of ultra-productive algal strains) are needed to achieve sustainable, large-scale algal biofuel production.

The next four chapters in the book deal with specific aspects of technology of direct relevance to biofuel production from algae. Chapter 6, by Ryan W. Hunt (The University of Georgia, Athens, USA) *et al.*, reviews the use of electromagnetic bio-stimulation as applied to bioenergy applications and provides a wealth of examples to show how growth may be stimulated by electromagnetic effects. The mechanisms responsible for these effects and the potential to apply to biofuel production are not fully understood; as the authors state, the aim of the paper is to stimulate interest in this field.

In Chapter 7, Juan Carlos Serrano-Ruiz (Universidad de Córdoba, Spain) *et al.* present an excellent overview of the potential catalytic transformations of two biomass derived acids for the production of advanced biofuels. The initial part of the chapter gives a brief outline of the chemistry involved in the catalytic processing of these resources, including both deoxygenation and carbon–carbon coupling reactions. The chapter then focuses on two platform chemicals, lactic acid and levulinic acid with a range of different transformations described to produce liquid hydrocarbon fuels for diesel and gasoline applications (**Figure 1**). The article also provides a very useful reference source with a good selection of recent articles on a variety of catalytic routes. However, discussion of the limitations of current catalytic technology and the advances required to deliver economically attractive processes to advanced biofuels is limited and would have been a useful addition to this chapter.

In Chapter 8, the use of anion exchange resins for one-step processing of algae is presented by Jessica Jones (The University of Texas at Austin) *et al.* The study shows that anion exchange resins such as Amberlite can concentrate and dewater algae and then be eluted with 5% sulfuric acid/methanol reagent. Although probably interesting to researchers in the field, this chapter is possibly too in-depth for the general reader.

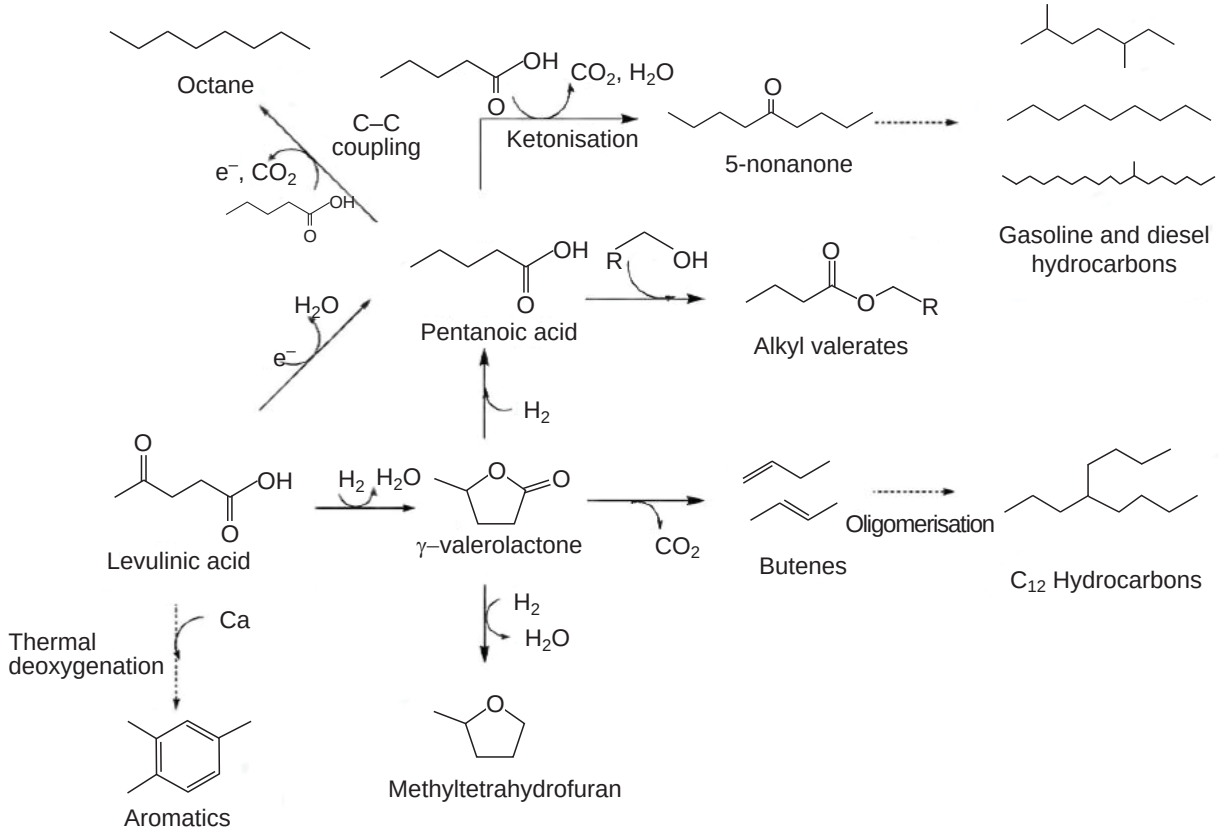


Fig. 1. Scheme of the catalytic routes required to convert biomass-derived acids such as lactic acid and levulinic acid into advanced biofuels

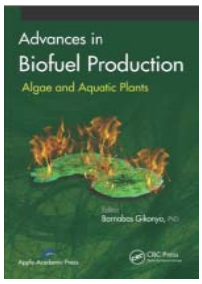
A comprehensive review of methods for microalgae isolation and selection for prospective biodiesel production is presented in Chapter 9. This is a useful, very readable general introduction to the subject for scientists working in this area who are not familiar with the fundamentals of isolation and selection of microalgae for commercial cultivation. The chapter highlights topics from isolation through to large-scale production. Subjects such as sampling and isolation of cultures as well as cultivation and lipid determination are thoroughly discussed using a number of examples. The chapter concludes with discussing lipid content and lipid extraction in microalgae. It highlights the range of lipid contents for various species and also explains that lipid productivity is not the only factor that should be considered during strain selection.

Next Generation Research

The final section of the book consists of three chapters under the theme of next generation research and the technical aspects of these chapters lie outside of the experience of the reviewers. Chapters 10 and 11, which provide a comparison of next generation sequencing systems and a review of an annotation tool, are likely to be of limited interest to the general reader. In contrast, the final chapter, which provides an example of the use of gene transcription to provide insight into metabolic pathways within microalgae, is more accessible. Even to the non-specialist, this paper illustrates the potential for future research into metabolic engineering to deliver microalgae with enhanced characteristics for sustainable fuel production.

Conclusions

Overall the book is an interesting combination of diverse papers dealing with the general topic of biofuel production from algae. This is a wide ranging subject and for the reader interested in detail of the latest technology in, for example, bioreactor design, upgrading catalysis and separations, the book will fall short of expectations. For those interested in a higher level overview of the opportunities for biofuel production from algae, the current limitations and the major themes where development effort is required, this book will provide a useful introduction to the subject.



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The Reviewers

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