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# Biohydrogen Production: Sustainability of Current Technology and Future Perspective



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Editors

Biohydrogen  
Production:  
Sustainability of Current  
Technology and Future  
Perspective

 Springer

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## Foreword



At the beginning of the twenty-first century, there are two important and interrelated global problems facing the humankind. They are the depletion of fossil fuels (coal, petroleum and natural gas) and the environmental problems caused by their utilisation. According to the best estimates, most of the fossil fuels, which can be extracted at a reasonable cost, will be depleted by the end of this century. The utilisation of fossil fuels is resulting into huge environmental problems, such as climate change, global warming, ozone layer depletion, acid rains, pollution, oxygen depletion and others. Carcinogens produced by the combustion of fossil fuels are many times more than those produced by cigarettes. Radioactivity produced by coal burning is many times greater than those produced by nuclear power plants. We are observing more frequent and stronger hurricanes, typhoons and tornadoes. We are also observing more and more droughts and floods. As global warming grows, they will also grow in size and frequency. Oceans are rising due to melting glaciers and ice caps. It is estimated that the cost of worldwide environmental and health damages caused by fossil fuels is presently 8 trillion US dollars per year and is growing.

There is an elegant solution to the above-described global problems. It is replacing the fossil fuels by hydrogen produced from clean and renewable energies. Hydrogen is the most efficient, the cleanest and the lightest fuel. It is also renewable. Once we convert to the hydrogen energy system, we shall never have to convert to another energy system, as we shall never run out of hydrogen. So long as we have the sun and renewable energy sources, we shall be able to produce clean and abundant hydrogen.

Of course, hydrogen is a synthetic fuel and it must be manufactured. There are various hydrogen manufacturing methods such as direct thermal, thermochemical, electrochemical, biological, etc. Among the hydrogen production methods, the biological method has the potential of producing the most cost-effective hydrogen. Because of this, many research groups around the world are working on biological hydrogen production. In several cases, bench-scale production systems have come up with encouraging results.

Clearly, time has arrived for a book on biohydrogen production. I congratulate the editors, Dr. Anoop Singh and Dr. Dheeraj Rathore, for seeing the need for such a book and producing it. This book entitled “Biohydrogen Production: Sustainability of Current Technology and Future Perspective” covers the biological hydrogen production authoritatively from A to Z, including raw material sources, various production technologies, sustainability problems, regional variations, economics, global trends and future perspectives.

I strongly recommend this excellent book to energy scientists, engineers and students, who are interested in hydrogen production in general and biological hydrogen production in particular, as well as to those with industrial concerns, who are looking for inexpensive hydrogen production technologies.



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## Preface

Presently most of the energy demand is fulfilled by the fossil fuel. Global petroleum demand has increased steadily from 57 million barrels day<sup>-1</sup> in 1973 to 90 million barrels day<sup>-1</sup> in 2013 and will continue to increase in line with the world's economy. The increasing energy demands will speed up the exhaustion of the finite fossil fuel. United Arab Emirates, one of the major oil export countries, would fail to meet the share in the oil and natural gas demands by 2015 and 2042, respectively. The fossil fuel resources in Egypt would be exhausted within two decades.

Using petroleum-based fuels creates atmospheric pollution during combustion. Apart from emission of the greenhouse gas (GHG) CO<sub>2</sub>, air contaminants like NO<sub>x</sub>, SO<sub>x</sub>, CO, particulate matter and volatile organic compounds are also emitted which leads not only to climate change but also to deterioration of environmental and human health. Continued use of fossil fuel is now widely recognised as unsustainable. A renewable, carbon-neutral energy resource is necessary for environmental and economic sustainability. Concern for exhausting the availability of fossil fuel for fulfilling future energy demand and considering changes in global climate by conventional energy resource has diverted researchers towards exploring a way to environmentally safe and sustainable energy resources. Finding sufficient supplies of clean energy for the future is one of the most daunting challenges for humanity and is intimately linked to global stability, economic prosperity and quality of life. A rapid surge in research activities with intensive focus on alternative fuels has been seen in the past decades in order to reduce the dependency on fossil fuels, mainly by providing local energetic resources.

Biofuels are considered as the most environment friendly alternative energy source because they are renewable and also sequester carbon. Currently, biofuels are commercially produced from the food crops, developing serious ecological and socio-economical anxiety such as land use changes and food-fuel competition issue. About 1% (14 million hectares) of the world's arable land is able to produce current biofuels, to supply 1% of global transport fuel demand. Between 1980 and 2005, worldwide production of biofuels increased by an order of magnitude from 4.4 billion litres to 50.1 billion litres. Clearly, increasing the share, it will be impractical due to the severe impact on the world's food supply and the large areas of production land required. This is manifested by the recent increase in grain prices due to utilisation of maize at large scale as a feedstock for production of fuel ethanol in the USA. This caused riots in Mexico due to the increase in the price of

tortillas, a staple food. Further, GHG saving is another constraint for developing a sustainable biofuel. The Intergovernmental Panel on Climate Change has calculated that reductions of 25–40% of CO<sub>2</sub> emissions by 2020 and up to 80% by 2050 are required to stay within temperature range, i.e. less than 2 °C, to avoid dangerous climate changes worldwide. The production of sustainable bioenergy is a challenging task in the promotion of biofuels for replacing the fossil-based fuels to get a cleaner environment and also to reduce the dependency on other countries and uncertainty of fuel price.

Among the various renewable energy sources, biohydrogen is a strong candidate for future energy source by virtue of the fact that it is renewable, does not evolve GHG and ozone layer-depleting chemicals in combustion, liberates large amount of energy per unit weight in combustion and is easily converted into electricity by fuel cell. Hydrogen is also harmless to mammals and the environment. Hydrogen can be produced safely and considered as the ultimate cleanest energy carrier to be generated from renewable sources. Progress in the late 1990s contributed to a breakthrough in terms of sustainable hydrogen production. There are various technologies (direct biophotolysis, indirect biophotolysis, photo-fermentations and dark fermentation) available for the production of biohydrogen from biomass/organic wastes, and many of these technologies have some drawbacks (e.g. low yield, low production rate, etc.), which limit the practical application. Studies on the biohydrogen production have been focused on photo-decomposition of organic compounds by photosynthetic bacteria, dark fermentation from organic compounds with anaerobes and biophotolysis of water using algae and cyanobacteria. Among these technologies, metabolic engineering is presently the most promising for the production of biohydrogen as it overcomes most of the limitations in other technologies. The biohydrogen production from biomass is particularly suitable for a relatively small and decentralised system, and it can be considered as an important key for a sustainable renewable energy source.

The present book is an effort to provide an up-to-date information and knowledge on the state of the art of biohydrogen production technology by the internationally recognised experts and subject peers in different areas of biohydrogen. It is a comprehensive collection of chapters related to choices of feedstock, microbiology, biochemistry, molecular biology, enzymes and metabolic pathways involved, bioprocess engineering, waste utilisation, economics, life cycle assessment and perspectives of the biohydrogen production in different countries and regions of the world and also include scale-up and commercialisation issues. The introductory chapter (Chap. 1) gives a general background for global energy statistics, available sources for energy supply, options of renewable energy sources, benefits of adoption of biohydrogen and its sustainability and future perspectives. The following chapter (Chap. 2) reviews the potentiality of different biomass that can be utilised for biohydrogen production and also discusses various technologies for production of biohydrogen and sums up with the required further research. Chapters (3 and 4) focused on biohydrogen production from agricultural biomass and wastes to analyse their suitability for biohydrogen production and also point out the challenges for biohydrogen production from agricultural biomass and wastes.

A series of chapters (Chaps. 5, 6, 7 and 8) are concentrated on the potential of microbial biohydrogen production especially from cyanobacteria and green algae. These chapters discussed on the physiology of biohydrogen production from microbial biomass, industrial approaches for biohydrogen production by photoautotrophic microbes, characterisation and identification of algal strains, mechanism of hydrogen photoproduction by algae, design and modelling of photobioreactor for algae cultivation and biohydrogen production, algal engineering for improving photosynthetic efficiency and hydrogenase and constraints and challenges for biohydrogen production. The following chapter (Chap. 9) is an attempt to review the latest findings on hydrogenase enzyme, responsible for hydrogen production, and also enlighten the metabolic engineering to increase the enzyme production and activity. Two chapters (Chaps. 10 and 11) reviewed the present status and future perspectives of biohydrogen production in Asia and Saudi Arabia. The economics, a major limitation of biohydrogen popularity for industrial production, is also covered (Chap. 12). Life cycle assessment (LCA) techniques allow detailed analysis of material and energy fluxes on regional and global scales. LCA studies of renewable energy sources calculate the environmental impact and can relate the results against sustainability criteria. The comprehensive LCA of biohydrogen production and its comparison with other biofuels is covered in the Chap. 13 and can be a tool for sustainability assessment and policy decisions. Chapter 14 presented a global trend of biohydrogen research and its future perspectives.

This book is aimed at a wide audience, mainly researchers, energy specialists, academicians, entrepreneurs, industrialists, policymakers and others who wish to know the latest development and future perspectives of biohydrogen production, and also discusses the bottlenecks of the various processes that currently limit the scale-up and commercialisation. Each chapter begins with a fundamental explanation for general readers and ends with in-depth scientific details suitable for expert readers. The text in all the chapters is supported by numerous clear, illustrative and informative diagrams, flow charts and comprehensive tables detailing the scientific advancements, providing an opportunity to understand the process thoroughly and meticulously. Written in a lucid style, the book comprehensively covers each point to give the reader a holistic picture about biohydrogen production technology and its sustainability. The book may even be adopted as a textbook for university courses that deal with biohydrogen and renewable energy sources.

Despite the great efforts of authors and editors along with extensive checks conducted by many experts in the field of biohydrogen production, mistakes may have been made. We would appreciate if the readers could highlight mistakes and make comments or suggestions to improve and update the book contents for future editions.

New Delhi, India  
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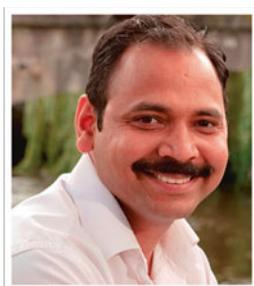
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