

167

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In references, *Advances in Biochemical Engineering/Biotechnology* is abbreviated as *Adv. Biochem. Engin./Biotechnol.* and cited as a journal.

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Falk Harnisch • Dirk Holtmann

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Bioelectrosynthesis

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Preface

The transformation of our current fossil fuel-based economy—and hence society as a whole—depends on different factors. Each of these factors, such as the biobased economy, bioeconomy, circular economy, and sustainable economy, slightly emphasizes one aspect over the others. However, they stand united when it comes to one point: the material resources and energy carriers that are exploited each year need to be recovered by nature within a similar time frame. In the words of Wilhelm Ostwald, who won the Nobel Prize in 1909: “*Die dauerhafte Wirtschaft muß ausschließlich auf die regelmäßige Benutzung der jährlichen Strahlungsenergie begründet werden* [The permanent economy has to be based solely by the utilization of the annual solar energy]” [1].

The generation of electric energy from renewable resources, such as photovoltaics or wind turbines, is already an advanced technology. However, its storage and transformation to chemicals in electrochemical reactions is a key challenge. Furthermore, because of its versatility and inherent advantages for a green economy, biotechnology is undisputed as a key technology of the twenty-first century. This nexus of electric energy and biobased chemicals is the essence of electrobiotechnology or bioelectrotechnology.

Biotechnology on its own is a highly interdisciplinary scientific discipline that embraces areas such as microbiology, chemistry, molecular biology, genetics, bioinformatics, and engineering sciences. It becomes even more complex for the integration of electrochemical reactions catalysed by biological moieties. These enzymatic or microbial electrochemical reactions are based on the interfacing of enzymes and whole cells with electrodes. The archetype of the respective devices—bioelectrochemical systems—is the microbial fuel cell (MFC), which generates electric energy from resources such as waste water. MFCs were first described more than 100 years ago. In recent decades, a plethora of applications in electrobiotechnology were proposed using bioelectrosynthesis—that is, the production of fine and platform chemicals based on enzymatically or microbially catalyzed

reactions driven by electric energy (as the most prominent example). However, for bringing microbial and enzymatic electrosynthesis from the laboratory bench to industrial applications, we must address the inherent complexity of the complete process chain.

The aim of the book *Bioelectrosynthesis* is to address the experimental state of the art, the envisaged applications, and the routes to close the current knowledge gap between them. The high interdisciplinarity in the research and development of microbial and enzymatic electrosynthesis is reflected in the conception and diverse content of the chapters within. This book aims to complement the large number of publications on biofuel cells and the specific aspects of electrobiotechnology. We hope that it can stand as a single authoritative source because, for the first time, it brings together the relevant developments in the field of bioelectrosynthesis. We intend to address scientists who are already active in this field as well as those who want to familiarize themselves with this fascinating area. Furthermore, this book is addressed to scientists who focus only on one of the previously mentioned disciplines. We hope they can transfer their knowledge, methods, and findings to the wealth of electrobiotechnology. This book may also contain some helpful information for stakeholders, funding agencies, and policy advisors.

Finally, the editors hope that this book will stimulate the growth and flourishing of the promising field that has gathered under the umbrella of the International Society of Microbial Electrochemistry and Technology.

Leipzig, Germany
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Falk Harnisch
Dirk Holtmann

Reference

1. Ostwald W (1909) Energetische Grundlagen der Kulturwissenschaft. Verlag von Dr. Werner Klinkhardt, Leipzig, p 44

Contents

Electrification of Biotechnology: Status quo	1
Falk Harnisch and Dirk Holtmann	
Extracellular Electron Transfer and Biosensors	15
Francesca Simonte, Gunnar Sturm, Johannes Gescher, and Katrin Sturm-Richter	
Electron Transfer Between Enzymes and Electrodes	39
Tanja Vidakovic-Koch	
Enzyme-Based Electrobiotechnological Synthesis	87
Lisa Marie Schmitz, Katrin Rosenthal, and Stephan Lütz	
Engineering of Microbial Electrodes	135
Sven Kerzenmacher	
Microbial Electrosynthesis I: Pure and Defined Mixed Culture Engineering	181
Miriam A. Rosenbaum, Carola Berger, Simone Schmitz, and Ronny Uhlig	
Mixed Culture Biocathodes for Production of Hydrogen, Methane, and Carboxylates	203
Annemiek ter Heijne, Florian Geppert, Tom H.J.A. Sleutels, Pau Batlle-Vilanova, Dandan Liu, and Sebastià Puig	
Reactors for Microbial Electrobiotechnology	231
Thomas Krieg, Joana Madjarov, Luis F.M. Rosa, Franziska Enzmann, Falk Harnisch, Dirk Holtmann, and Korneel Rabaey	
Modeling Microbial Electrosynthesis	273
Benjamin Korth and Falk Harnisch	
Electrochemical Applications in Metal Bioleaching	327
Christoph Kurt Tanne and Axel Schippers	

Generating Electric Current by Bioartificial Photosynthesis 361
Babu Halan, Jenny Tschörtner, and Andreas Schmid

Electrification of Biotechnology: Quo Vadis? 395
Dirk Holtmann and Falk Harnisch

Erratum to: Engineering of Microbial Electrodes 413
Sven Kerzenmacher

Index 415

About the Editors

Falk Harnisch is a group leader at the Helmholtz Centre for Environmental Research – UFZ in Leipzig (Germany), a post he has occupied since 2012. He earned his PhD in Environmental Chemistry (2009) and a Diploma in Biochemistry (2006), both from the University of Greifswald (Germany), and his Habilitation in Biophysical Chemistry (2016) from the University of Leipzig. He has received numerous awards and scholarships, most recently the Biotechnology 2020+ research award from the German Federal Ministry of Education and Research (2012), and a research award from the Helmholtz Centre for Environmental Research – UFZ (2015). Prior to his current post he was a post-doctoral fellow and senior researcher at the Braunschweig University of Technology (Germany) and a visiting academic at the University of Queensland (Australia). He has now been working at the interface of microbiology and electrochemistry for over a decade. His research interests cover the fields of microbial electrochemistry and microbial electrochemical technologies, as well as electrochemistry for energy conversion and storage, especially electroorganic chemistry.

Dirk Holtmann was born in Bremen, Germany, and completed his diploma in chemical engineering/biotechnology in 1999 at University of Applied Science Emden. He obtained his PhD, on the electrochemical measurement of microbial activities in fermentation, at the Otto von Guericke University of Magdeburg. He is now group leader of the biochemical engineering group at the DECHEMA Research Institute in Frankfurt, Germany. The group's research focuses on combinations of different disciplines – such as bio-, electro-, and chemocatalysis; molecular biology; and process engineering – to develop novel production routes. His current research activities concentrate on biocatalysis and biotransformation, with the development and evaluation of electroenzymatic processes, as well as microbial electrosynthesis.