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INTRODUCTION

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During the past century, energy consumption has increased so dramatically that an unbalanced energy management scenario now exists. We are now aware of the transience of nonrenewable resources and the irreversible damage caused to the environment through their collection and use. There is no sign that this growth in demand will abate as global industrialization and the consumer culture expand. The call for resources to satisfy economies and individual requirements will outpace supply of classic resources. In addition, there is a trend toward the miniaturization and portability of computing and communications devices. These energy-intense applications require small, lightweight power sources that will sustain operation over long periods of time, even in remote locations separated from "civilization," such as military engagement and exploration. Biological fuel cells (BFCs) may provide a solution to provide small, lightweight, sustainable sources of power using simple renewable fuels (sugars, alcohols). BFCs have two primary operational advantages over alternative technologies for generating power from organic substrates: high

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conversion efficiency and operation at ambient temperatures. Furthermore, BFCs will scale down more effectively than conventional batteries. That scaling complements advances in the medical sciences, which are leading to an increased prevalence of implantable electrically operated devices (e.g., pacemakers). These items need power supplies that can operate for long period of time, so as to avoid issues with maintenance or replacement that would require surgery. Ideally, implanted devices would take advantage of the natural substances found in the body, thus deriving power from a continuous and renewable fuel source. BFCs potentially offer solutions to all these challenges, by applying Nature's solutions to energy conversion and tailoring them to meet specific power requirements. Because BFCs use concentrated sources of chemical energy, and will operate at high conversion efficiency, these devices can be small and lightweight, particularly when the fuel is derived directly from a living organism (e.g., glucose from the bloodstream), or harvested from the environment ("fuel scavenging").

Conventional fuel cells use inorganic catalysts and precious metals in anodic and cathodic half-reactions separated by a barrier that selectively allows passage of positively charged ions. BFCs follow the same basic principle, but biological molecules (redox enzymes or whole microbial cells) catalyze the electrochemical processes. Microbial BFCs require continuous maintenance of whole living cells to sustain physiological processes, and as a result, dictate stringent working conditions to maintain output. To overcome this constraint, the redox enzymes responsible for desired processes may be separated and purified from living organisms and directly applied as biocatalysts in BFCs. The resulting systems, termed enzymatic fuel cells (EFCs) use specific enzymes that when electrically contacted with an electrode will oxidize energy-rich abundant organic raw materials, such as alcohols, organic acids, or sugars, in the anode. In the cathode, substrates such as molecular oxygen (O_2) or hydrogen peroxide (H_2O_2) are reduced. In combination with the anodic reaction, this process generates electrical power (voltage and current). Enzymes are environmentally sensitive, however, and may degrade over time when exposed to the environment, and as a result, special ways for stabilization and utilization must be established. Advances in characterizing and manipulating nanomaterial architectures, for example, provide enhanced connectivity at the biomaterial interface.

Undeniably, EFCs are a rapidly developing area of scientific research and technological development. Within the last decade, publications concerning optimization and characterization of anodic and cathodic biocatalysts have risen by an order of magnitude (e.g., 3 manuscripts in 2002 compared with >30 in 2010).

This book will address BFC technology in five distinct sections:

1. Introduction to EFC.
2. Fundamentals of EFC.
3. Optimizing and characterizing biological catalysis.
4. System design and integration.
5. Outlook to future development and emerging applications.

The utility of BFCs is determined largely by service life and power density. Accordingly, maximizing the lifetime of catalysts by effective electrocatalytic association with electrodes is essential to EFC development. There are numerous biochemical and biophysical facets of EFCs that can be optimized to enhance their efficiency and power, and many of those factors will be discussed and presented herein.

BFCs have evolved exponentially over the past decade and are emerging as a simple and robust technology for generating power that is limited only by device engineering. Provided the biological understanding increases, the electrochemical technology advances, and the overall electrode prices decrease, this concept may soon qualify as a core technology for conversion of carbohydrates to electricity.

LIST OF ABBREVIATIONS

BFC	biological fuel cell
EFC	enzymatic fuel cell