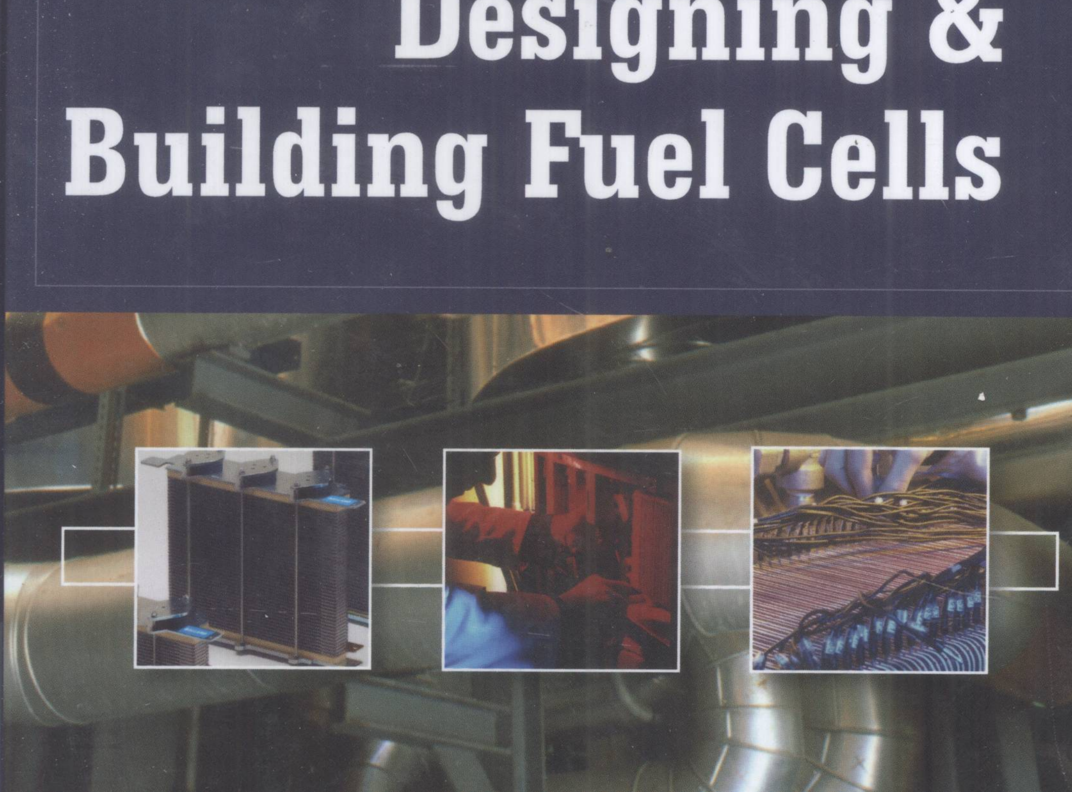
Colleen S. Spiegel

Designing & Building Fuel Cells



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To my husband, Brian,
who inspires me to be a better person every day,
encourages me to pursue all of my dreams,
and has the patience and endurance to stand by me
while I work at them.

To my unborn son, Howard,
who had to endure endless sleepless nights with me
while completing this book.

ABOUT THE AUTHOR

Colleen S. Spiegel is the founder of Clean Fuel Cell Energy, LLC. She has been an R&D manager and chemical engineer for more than seven years, and has expertise in the areas of fuel cell design and modeling. Ms. Spiegel is a member of the American Institute of Chemical Engineers (AICHE) and the Institute of Electrical & Electronic Engineers (IEEE).

Foreword

The creation and consumption of energy is a necessity in today's world. It has drastically increased the quality of life of modern society and has allowed the rapid advancement of modern technology. The majority of energy required to power our homes, offices, and automobiles is created from fossil fuels, and though they are essential to our society, use of fossil fuels has also resulted in increased health risks and global warming. Their diminishing supply is also causing international tension and contributing to high inflation. Thankfully, fuel cell technology has the potential to meet the energy needs of our ever-growing population, resolve many of the conflicts fossil fuels are causing, and will accomplish these goals in an environmentally friendly way.

During the last decade, fuel cells have been researched and developed more quickly than at any time since their discovery in 1839. Interest in them has increased tremendously as international tensions have intensified due to increasing fossil fuel prices, the scarcity of fossil fuels, the power of countries with national fossil fuel resources, and the threat of global warming. The study of fuel cells crosses many academic disciplines, such as mechanical, chemical, environmental, and electrical engineering, as well as chemistry and material science. The writing of this book was motivated by the need to have a practical, informational fuel cell reference that could aid someone who has never built a fuel cell before, yet provide enough theory to help accurately design a state-of-the-art fuel cell.

The primary audience of this textbook is professional engineers and scientists who need an all-encompassing fuel cell guide. It is also intended for the professional or student who wants to design and build commercial-grade fuel cells; therefore, it incorporates a unique balance of theory, practical knowledge, and design. This book is also meant to be an engineering or science text, and it includes examples and problems to help students bridge the gap between the various interdisciplinary sciences needed to accurately design and build fuel cells.

The text is organized into 17 chapters. The first four chapters provide an overview of fuel cell technology, types, applications, and offers a peek at the coming hydrogen economy. The first chapter describes the basics of fuel cells and compares them with batteries and heat engines, outlining fuel cell markets, and the history and fundamentals of how fuel cells work. Chapter 2 describes fuel cells and the hydrogen economy. It compares hydrogen with other fuel types, and describes how the hydrogen economy can be developed. Hydrogen production, storage, and distribution are discussed, as well as those countries working on building a hydrogen economy. Chapter 3 describes different fuel cell types. It also explores a few fuel cell types sometimes not considered fuel cells, or that are in mostly the R&D stage. Chapter 4 discusses the main applications of commercial and R&D fuel cells such as portable power, backup power, transportation, and stationary power applications.

Chapters 5 through 9 provide an introduction to the necessary science involved in predicting fuel cell performance. Chapter 5 covers basic fuel cell thermodynamics and demonstrates the calculation of theoretical fuel cell voltage, theoretical fuel cell efficiency, fuel cell temperature, and pressure. Chapter 6 describes the basics of fuel cell electrochemistry and introduces electrode kinetics, voltage losses, internal and crossover currents, and improved kinetic performance. Chapter 7 explores fuel cell charge transport especially in fuel cell electrolytes, while Chapter 8 covers fuel cell mass transport and specifically discusses diffusive transport in fuel cell electrodes, convective transport in flow channels, and concentration polarization. Chapter 9 is devoted to heat transfer, and covers the topics of energy balance, heat conduction, active heat removal, stack heat dissipation, and stack cooling options. Chapter 10 describes fuel cell modeling and uses the concepts outlined in Chapters 5 through 9 to model the fuel cell layers.

Chapters 11 through 14 discuss the basic materials and plant subsystems used for building a fuel cell system. Chapter 11 details state-of-the art fuel cell materials for the electrolyte, catalyst, and electrode layers, and explores processing techniques for creating the fuel cell. Chapter 12 tackles fuel cell stack components and materials, and specifically discusses bipolar plate materials, flow-field design, channel shape, and dimensions. It also delves into bipolar plate manufacturing techniques, gaskets, and end plates. Chapter 13 is about fuel cell design and explores stack sizing, the number of cells, stack configuration, cell interconnection, stack clamping, and how to put a fuel cell stack together. Chapter 14 covers fuel cell system design and introduces fuel cell plant components and the electrical parts of the system.

The remaining chapters (15 to 17) explain fuel types, fuel cell operating conditions, and testing. Chapter 15 compares fuel types, storage, and processing. It specifically covers hydrogen, methanol, ethanol, metal hydrides, chemical hydrides, ammonia, propane, and petroleum-based fuels. Chapter 16 shows how to calculate fuel cell operating conditions based upon operating temperature, pressure, flow rates, humidity, and mass balances. Finally, Chapter 17 summarizes popular methods of characterizing fuel cells and describes common fuel cell test methods.

I would like to acknowledge all of the teachers, engineers, and scientists that have contributed to my learning and knowledge of this subject. I also want to express my heartfelt gratitude to my husband for his continued patience, understanding, and encouragement throughout the writing of this text, and for being a loving partner as we move on toward life's other goals together.

Colleen Spiegel
Clearwater, Florida, USA

Contents

Chapter

1

An Introduction to Fuel Cells

The current movement towards environmentally friendlier and more efficient power production has caused an increased interest in alternative fuels and power sources. Fuel cells are one of the older energy conversion technologies, but only within the last decade have they been extensively studied for commercial use. The reliance upon the combustion of fossil fuels has resulted in severe air pollution, and extensive mining of the world's oil resources. In addition to being hazardous to the health of many species (including our own), the pollution is indirectly causing the atmosphere of the world to change (global warming). This global warming trend will become worse due to an increase in the combustion of fossil fuels for electricity because of the large increase in world population. In addition to health and environmental concerns, the world's fossil fuel reserves are decreasing rapidly. The world needs a power source that has low pollutant emissions, is energy efficient, and has an unlimited supply of fuel for a growing world population. Fuel cells have been identified as one of the most promising technologies to accomplish these goals.

Many other alternative energy technologies have been researched and developed. These include solar, wind, hydroelectric power, bioenergy, geothermal energy, and many others. Each of these alternative energy sources have their advantages and disadvantages, and are in varying stages of development. In addition, most of these energy technologies cannot be used for transportation or portable electronics. Other portable power technologies, such as batteries and supercapacitors also are not suitable for transportation technologies, military applications, and the long-term needs of future electronics.

The ideal option for a wide variety of applications is using a hydrogen fuel cell combined with solar or hydroelectric power. Compared to other fuels, hydrogen does not produce any carbon monoxide or other pollutants. When it is fed into a fuel cell, the only by-products are oxygen and heat. The oxygen is recombined with hydrogen to form water when power is needed.

Fuel cells can utilize a variety of fuels to generate power—from hydrogen, methanol, and fossil fuels to biomass-derived materials. Using fossil fuels to generate hydrogen is regarded as an intermediate method of producing hydrogen, methane, methanol, or ethanol for utilization in a fuel cell before the hydrogen infrastructure has been set up. Fuels can also be derived from many sources of biomass, including methane from municipal wastes, sewage sludge, forestry residues, landfill sites, and agricultural and animal waste.

Fuel cells can also help provide electricity by working with large power plants to become more decentralized and increase efficiency. Most electricity produced by large fossil-fuel burning power plants are distributed through high voltage transmission wires over long distances [1]. These power plants seem to be highly efficient because of their large size; however, a 7 to 8 percent electric energy loss in Europe, and a 10 percent energy loss in the United States occurs during long distance transmission [1]. One of the main issues with these transmission lines is that they do not function properly all the time. It would be safer for the population if electricity generation did not occur in several large plants, but is generated where the energy is needed. Fuel cells can be used wherever energy is required without the use of large transmission lines.

Fossil fuels are limited in supply, and are located in select regions throughout the world. This leads to regional conflicts and wars which threaten peace. The limited supply and large demand dries up the cost of fossil fuels tremendously. The end of low-cost oil is rapidly approaching. Other types of alternative energy technology such as fuel cells, can last indefinitely when non-fossil fuel–based hydrogen is used.

This chapter discusses the basics of fuel cells:

- What is a fuel cell?
- Why do we need fuel cells?
- The history of fuel cells
- How do fuel cells work?

By discussing the fuel cell basics, one can appreciate the relevance and significance of fuel cells in addressing environmental and industrial problems, as well as the physical and chemical mechanisms that underlie fuel cell operation.