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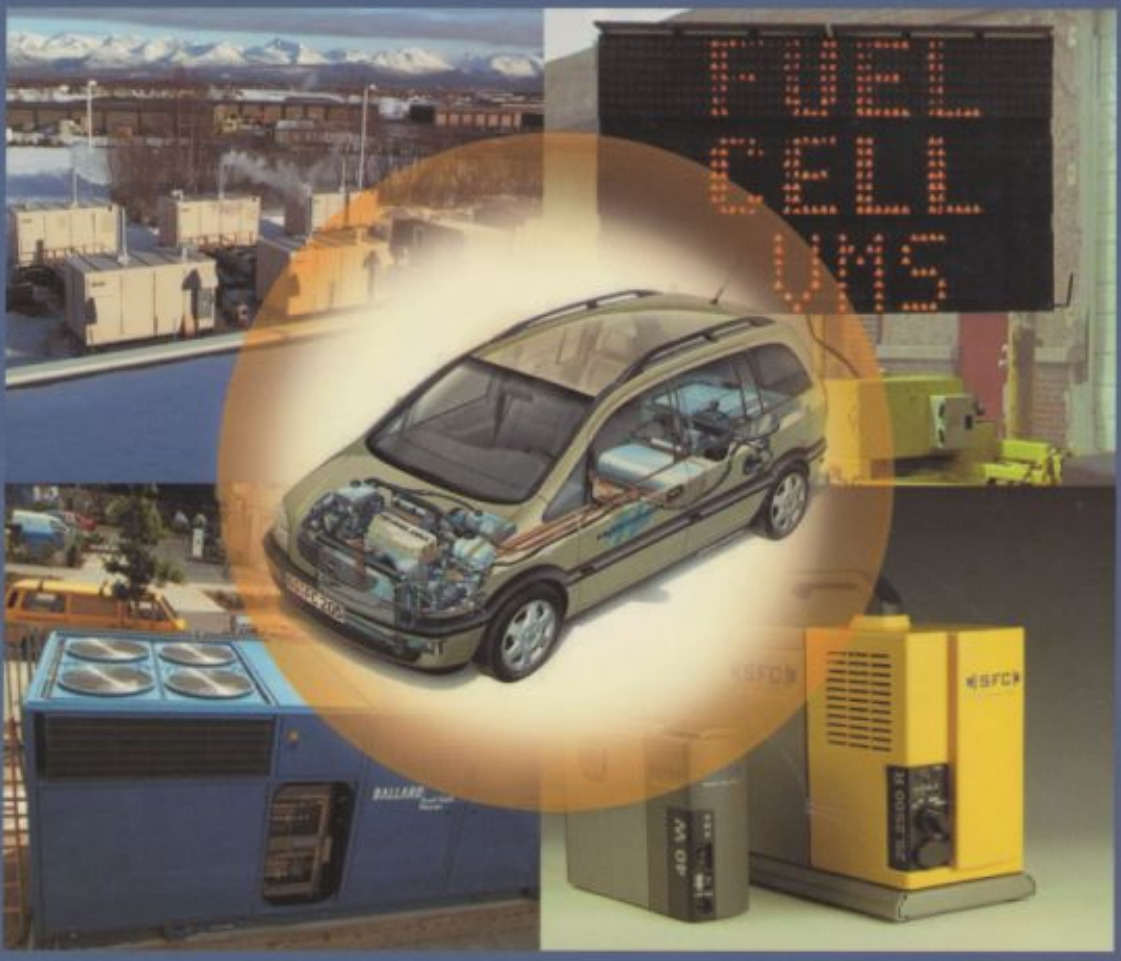
FUEL CELL TECHNOLOGY HANDBOOK



Edited by

Gregor Hoogers

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Boca Raton London New York Washington, D.C.

Library of Congress Cataloging-in-Publication Data

Fuel cell technology handbook / edited by Gregor Hoogers.
p. cm.
Includes bibliographical references and index.
ISBN 0-8493-0877-1 (alk. paper)
1. Fuel cells. I. Hoogers, Gregor.
TK2931 .F785 2002
621.31'2429—dc21

2002067086

Direct all inquiries to CRC Press LLC, 2000 N.W. Corporate Blvd., Boca Raton, Florida 33431.

Visit the CRC Press Web site at www.crcpress.com

International Standard Book Number 0-8493-0877-1
Library of Congress Card Number 2002067086
Printed in the United States of America 1 2 3 4 5 6 7 8 9 0
Printed on acid-free paper

Dedication

To Frederike

Foreword

"Why write a book on fuel cell technology? The best medium for keeping updated is the Internet!"

This was the comment I received from a fuel cell pioneer when he heard about this project. It is true that every day now, technical and commercial developments are reported which certainly sound and in some cases truly are interesting, and that the Internet is a good medium to use for keeping up-to-date (a list of useful Internet links is given in the Appendix). But this has been the case for the past 15 to 20 years. While my co-authors and I were working on this book, two developers went out of business — and at least in one case, this did not come as a complete surprise to those who know a little about the technology. Those who are not fuel cell pioneers may find it hard to make a judgment about what fraction of the hard selling that is usually done in a business context is relevant, and it takes considerable time to do so. Also, how does one identify the leading developers? Despite all its wonders, the Internet has two crucial weaknesses: it does not provide a historic record, and no independent institution verifies the accuracy of a piece of information that is presented on the Web.

Another peculiarity of fuel cell technology is something I learned from my students which is that it is a very broad subject encompassing areas such as electrochemistry, chemical catalysis, materials science, polymer science, fluid dynamics, electrical and mechanical engineering, etc., which are usually not covered in a single textbook. The material presented here has formed the basis for a series of fuel cell lectures and short courses at Reading (U.K.), Birkenfeld (Germany), and Clemson, South Carolina (U.S.).

The first part of this handbook (Chapters 2–7) deals with the principles of fuel cell technology and gives an outline of its long and winding history (Chapter 2), which to the best of my knowledge has not been presented elsewhere. This part of the book gives a sound technology overview to the generally interested reader, technologist, student, or engineer. The information provided is the sum of roughly 5 decades of fuel cell research and captures the main concepts, development strands, and remaining technical problems with respect to the fuel cell and the overall fuel cell system, in particular the fueling aspect. The technology has now reached a degree of maturity, which is reviewed. A whole chapter is dedicated to the direct methanol fuel cell or DMFC, reflecting the relative importance of this technology in the context of portable systems (Chapter 7).

The second part of the book deals with the applications of fuel cell technology in automotive, stationary, and portable power generation (Chapters 8–10), and it reviews competing technologies (Chapters 11 and 12). Three chapters are dedicated to the three main applications. Each chapter is self contained and gives a sound overview of the main development strands, the prototypes, and the key players. Together with some of the information provided in the earlier chapters, these chapters provide a basis that will allow interested readers to form their own opinions on the question that people in the field are constantly asked: how many years away are fuel cells? Well, here is the answer: read this book! — I sincerely hope you will enjoy it.

It is a pleasure to thank those who made this project possible. First of all, I would like to thank my co-authors. As a rule, those making active contributions to the field are very busy people, and I am grateful they were able to dedicate some of their valuable time to this project.

I would also like to thank CRC Press and the SAE. Cindy Renee Carelli, acquisitions editor, Helena Redshaw, supervisor, Editorial Project Development, and Samar Haddad, Project Editor, of CRC Press provided constant help, encouragement, and nagging, which was sometimes needed. It was certainly an exciting time for all involved. In the process, I moved from industry to academia and sometimes saw my firstborn grow faster than the page numbers. Many thanks to Martina Hinsberger for her ceaseless communications with fuel cell developers who sent us graphical material and to all those who provided photographs, advice, and valuable information on their technology. Thanks also to those who taught me science and fuel cell technology: Dieter, Dave, Jack, and Tom. And to Astrid and Sebastian for their patience, and for being there.

Gregor Hoogers
Trier
July 2002

Editor

Dr. Gregor Hoogers is a full-time professor at Trier University of Applied Sciences, Umwelt-Campus Birkenfeld. After receiving his master's degree in physics from the Technical University of Aachen in 1990 for research on chemical sensors with C.D. Kohl, he joined the Debye Institute, Utrecht, as a postgraduate fellow working on base metal oxidation with F. Habraken. Subsequently, he studied elementary catalytic surface processes in D.A. King's group at Cambridge, U.K., from which he received his Ph.D. in 1994. From 1995 until 1999, he worked at Johnson Matthey Technology Centre, Reading, U.K., where his main interest was in the interaction of fuel processor, cleanup, and fuel cell and where, as principal scientist, he was in charge of anode technology for fuel cells. In October 1999, he was appointed professor for hydrogen technology and fuel cells/renewable energy at Trier University Umwelt-Campus Birkenfeld, where he became head of department in 2001. He is the author of 25 papers and a number of patents. In 2001, he received the Innovation Prize of Rhineland-Palatinate (Germany) for developing cost-effective bipolar plates.

Contributors

Dr. Ausilio Bauen is a research fellow at the Imperial College Centre for Energy Policy and Technology (ICCEPT) in London. He received a master's degree in physics engineering from the Swiss Federal Institute of Technology in Lausanne (EPFL) in 1993 and subsequently worked for the Solar Energy and Building Physics Laboratory of the EPFL. In 1995, he completed a master's degree in Environmental Technology and Energy Policy at Imperial College in London, during which his research focused on sustainable urban development. He completed a Ph.D. at King's College London on biomass energy systems in 1999. He has been collaborating with Imperial College on fuel cell projects since 1997, prior to joining ICCEPT in 1999. Since 1997 he has been a director of the specialist energy–environment consulting firm E4tech. His current research focuses on techno–economic, environmental, and policy aspects of fuel cell systems and related fuels; biomass energy systems; and renewable energy integration into energy systems. He has acted as an expert advisor to the U.K. Cabinet Office Performance and Innovation Unit, the Royal Commission on Environmental Pollution, and the European Commission's European Climate Change Programme.

Supported by a British Marshall Scholarship in 1998, **Eric Chen** earned his Ph.D. from the University of Oxford (U.K.) where he researched fuel cells and fuel processors in the Department of Engineering Science and in collaboration with the Johnson Matthey Technology Centre. He earned his undergraduate degree in mechanical engineeering from Vanderbilt University.

David Hart is head of fuel cells and hydrogen research at the Imperial College Centre for Energy Policy and Technology (ICCEPT) in London. He received a B.Eng. in mechanical engineering from the University of Bath in 1991 and subsequently worked in control systems engineering for Moog Japan Ltd., in Hiratsuka, near Tokyo. His M.Sc. thesis at Imperial College in 1994 investigated the use of fuel cells in distributed power generation, and his ongoing research is focused on fuel cell systems from the economic, environmental, policy, and infrastructure perspectives. His doctoral work closely examines the full fuel cycle emissions of fuel cell systems in the U.K. context, and he has published analysis in this area, with colleagues, commissioned by the U.K. Department of Trade and Industry. He is a member of the Grove Fuel Cell Symposium organizing committee, a member of the technical organizing committee of the World Hydrogen Conference in 2002, and a member of the roster of experts for the Scientific and Technical Advisory Panel of the Global Environment Facility. He is also a director of the specialist energy–environment consulting firm E4tech.

Martina Hinsberger is a graduate industrial engineer and has worked in the area of fuel cells since the year 2000. In 2000, at the Environmental Campus Birkenfeld, she wrote her diploma thesis on "Cost analysis and cost reduction potentials of fuel cell systems" for which she received the 2001 Student Award of the University of Applied Sciences, Trier. She then worked at the Research Centre Juelich in a DMFC research group. In 2001, she returned to Birkenfeld to join the biomass fuel cell research project of Prof. Gregor Hoogers. Recently, she started working in the sector of renewable energies (especially PV).

Dr. Martin Hogarth is a senior scientist at the Johnson Matthey Technology Centre and has worked in the area of direct methanol fuel cells (DMFCs) since 1992. He joined Johnson Matthey after receiving his Ph.D. from the University of Newcastle-upon-Tyne in 1996, where he was part of the DMFC research group of Professor Andrew Hamnett and Dr. Paul Christensen. His current interests are in the development of new electrocatalyst materials and high-performance membrane electrode assemblies (MEAs) and have recently expanded to include proton conducting polymers, particularly high-temperature and methanol impermeable materials for the proton exchange membrane fuel cell (PEMFC) and DMFC.

Richard Stone is a reader in engineering science in the department of engineering science at Oxford. He was appointed to a lectureship in Oxford in 1993, and for 11 years prior to that he was a lecturer/senior lecturer at Brunel University. His main interest is combustion in spark ignition engines, but he also has interests in fuel cells and the measurement of laminar burning velocities in zero gravity, and he is undertaking a longitudinal study of vehicle technology. This study commenced with 1970s technology 20 years ago but has now been extended back to the 1920s, with completion projected in 2020. He has written some 90 papers, mostly in the area of engine combustion and instrumentation, and he is well known for his book *Introduction to Internal Combustion Engines*, the third edition of which was published in 1999.

Dr. David Thompsett is a senior principal scientist at the Johnson Matthey Technology Centre, near Reading in the U.K., where he has been based since 1986. He currently leads a group responsible for the research and development of catalyst and membrane components for low-temperature fuel cells. He holds seven patents and has co-authored a number of publications. He has worked extensively on the development of fuel cell catalysts for phosphoric acid, proton exchange membrane, and direct methanol fuel cells, together with the development of catalyst technology for automotive and diesel emission control. He received his B.Sc. in chemistry and Ph.D. in inorganic chemistry from the University of Bath in the U.K.

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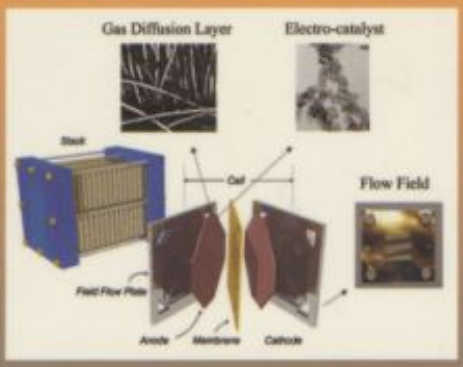

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Fuel cell systems have now reached a degree of technological maturity and appear destined to form the cornerstone of future energy technologies. But the rapid advances in fuel cell system development have left current information available only in scattered journals and Internet sites. The even faster race toward fuel cell commercialization further leaves the objectivity of many Internet articles open to question.

The ***Fuel Cell Technology Handbook*** provides the first comprehensive treatment of both the technical and commercial aspects of high and low temperature fuel cells, fuel cell systems, fuel cell catalysis, and fuel generation. It sets forth the principles of fuel cell technology and summarizes the main concepts, developments, and remaining technical problems, particularly in fueling. It explores applications in automotive, stationary, and portable power generation technologies and presents an expert's look at future developments in both the technology and its applications.

With chapters contributed by leading authorities working in academic and industrial R&D, this handbook forms a reliable basis for understanding fuel cell technology, applications, and commercial realities. Whether you're developing fuel cell components, designing a fuel cell system, or just interested in the viability of an application, the ***Fuel Cell Technology Handbook*** is the best place to start.

FEATURES

- Provides a thorough, up-to-date overview of fuel cell principles, technologies, and applications
- Uses clear explanations and abundant illustrations that make the information truly accessible
- Explores automotive, stationary power generation, and portable power applications, including in-depth coverage of hydrogen generation and storage
- Forms an ideal basis for a graduate course in fuel cell technology and business
- Furnishes Web links that will keep you in touch with fast breaking business developments

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ISBN 0-8493-0877-1

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