

# Preface

Modern societies are starving of energy to support their activities and growth. Today, the energy consumption of a country represents a reliable measure of its wealth and of its industrial development. The most industrialized countries consume about 20 MWh per capita per year while the world average energy consumption is only of 2.4 MWh/year. Today, 81 % of energy production comes from the exploitation and transformation of fossil fuels. These evidences suggest that we need to rethink both the way how energy is produced and its conversion into electricity with the aim to achieve a sustainable and balanced development for every nation. Valorization of renewable resources and distributed energy generation are very appropriate strategies to strike a balance between the growing energy demand and the need to reduce the environmental impact on human activities.

This requires the development of green technologies for the production of energy and for a rational and more efficient use of resources. Fuel cells, which convert chemical energy directly to electricity, offer higher efficiencies and significantly lower emissions than conventional technologies. The modular configuration of fuel cells makes these devices suitable for a wide range of potential applications, including combined heat and power (CHP) production, distributed power generation and transport, which reduces reliance on imports of primary energy carriers and encourages local productivity.

In a transitional phase from an economy based on the predominant use of fossil fuels to one capable of efficiently exploiting renewable sources, medium/high temperature fuel cells based on ceramic oxides (solid oxide fuel cells, SOFCs) can play a fundamental role in accelerating the transformation. Thanks to their ability of using hydrocarbon-based fuels, the increased durability, and higher tolerance to contaminants, these type of cells could be immediately implemented in the established grid infrastructure and therefore have a rapid market penetration on a large scale.

Considering this potential, in recent decades, both the public and private sectors have invested resources to bring SOFCs to the commercial and residential markets, albeit with limited success. Progress in price reduction and performance increase has remained incremental, and a real launch of the technology has long resided

“just around the corner.” Insufficient longevity, reliability, and especially prohibitive costs are the main issues to be addressed.

The challenge of making fuel cells reliable, lasting, and efficient stemmed from the complexity of how they work, which needs to be truly understood, requires an interdisciplinary approach integrating scientific and technical knowledge. Several examples suggest that this type of methodology could achieve ground-breaking discoveries that would ultimately lead to viable commercial products.

For this purpose, the education of a class of scientists and engineers aware of how the technology is progressing and able to tackle the current challenges is crucial. In view of such request, this book gathers and updates a series of lectures given at the “Advances in Medium and High temperature Solid Oxide Fuel Cell Technology” international school organized by the editors in cooperation with the International Centre for Mechanical Sciences (CISM) in July 2014 in Udine (Italy). The book presents an overview of the recent advances in the field of SOFC technology and is intended as an introduction to the challenging issues that need to be addressed.

The chapters are written by internationally renowned scientists currently working at the leading edge of fuel cell research and development, and cover several themes such as the fundamentals of fuel cell thermodynamics, materials and components properties, electrodic processes, and the modeling principles for SOFC systems.

In chapter “[Introduction to Fuel Cell Basics](#),” fundamental electrochemistry of medium- and high-temperature fuel cells (solid oxide fuel cell, SOFCs) is explained with emphasis addressed to different aspects of high-temperature solid-state electrochemistry compared to low-temperature electrochemistry.

Chapter “[Testing of Electrodes, Cells and Short Stacks](#)” illustrates how to obtain reliable, accurate and reproducible electrochemical measurements through a proper selection of cell geometries and set-up. Principles, benefits, and drawbacks of different characterization techniques are discussed. Moreover, the concept of area-specific resistance (ASR) and how direct and alternate current methods can be optimized to provide not only the total ASR but also an electrochemical characterization of specific components (electrolyte and electrodes) of a fuel cell are described. The authors conclude by introducing the readers to some of the approaches used to study the effects of impurities on cell performance and to the problem of gas leakage in high-temperature fuel cells.

Chapters “[Proton-Conducting Electrolytes for Solid Oxide Fuel Cell Application](#)” and “[Interconnects for Solid Oxide Fuel Cells](#)” deal with new categories of materials to achieve the target of making SOFCs efficiently operative at temperatures as low as 550–600 °C. To this end, proton-conducting oxides have attracted widespread interest as electrolyte materials, alternative to traditional oxygen ion conductors. Chapter “[Proton-Conducting Electrolytes for Solid Oxide Fuel Cell Application](#)” presents an overview of main advances in the field of solid oxide proton-conducting materials describing several classes of materials such as perovskite-based materials (e.g., doped  $\text{BaCeO}_3$ ,  $\text{BaZrO}_3$ ,  $\text{BaCeO}_3\text{-BaZrO}_3$ ,  $\text{SrCeO}_3$ ,  $\text{LaScO}_3$ ) or fluorite- or pyrochlore-based materials (e.g., doped  $\text{Ba}_2\text{In}_2\text{O}_5$ ,  $\text{CeO}_2$ ,  $\text{LaNbO}_4$ ). Composition,

transport, thermal and structural properties of the materials have been correlated with their conductivity and stability with the aim of indicating the most suitable materials for SOFC applications. Chapter “[Interconnects for Solid Oxide Fuel Cells](#)” deals with materials and strategies to prepare suitable interconnects. Authors illustrate the two main categories of interconnects: ceramic and metallic-type, pointing out advantages and disadvantages of both. The recent strategy of coating metallic interconnects with redox active oxide is also discussed.

In chapter “[Catalysts and Processes in Solid Oxide Fuel Cells](#),” physical and physicochemical properties of electrode materials are examined. It is pointed out that operation of anodes with fuels other than hydrogen (fossil and renewable fuels) is commercially necessary and challenging because of carbon deposition. The complex properties required for SOFC anodes are described, and issues related to nickel anode degradation are specifically addressed. The ultimate approach of producing stable direct oxidation in the anode is compared to the classical fuel reforming processes (internal and external to the anode), discussing advantages and disadvantages of the different methods.

The final chapters of the book discuss the SOFC technology in terms of an integrated system whose efficiency depends on several other subsystems. In this light, modeling is a key tool to design and optimize such systems avoiding extensive experimental investigations. Chapters “[Energy System Analysis of SOFC Systems](#),” “[DOE Methodologies for Analysis of Large SOFC Systems](#),” and “[Solid Oxide Fuel Cells Modeling](#)” describe the principle of mathematical modeling addressed to FC systems and processes optimization. The aim of Chapter “[DOE Methodologies for Analysis of Large SOFC Systems](#)” is to design experiment methodologies for analyzing large SOFC systems and the presentation of a case history using the CHP-100 kWe SOFC Field Unit (Siemens Power Generation-Stationary Fuel Cells) installed at TurboCare (Torino, Italy). Chapter “[Solid Oxide Fuel Cells Modeling](#)” provides an introduction to SOFC modeling using a macroscopic, physically based approach for the description of the chemical and electrochemical processes occurring at the electrodes.

We would like to thank all the authors for their valuable contribution to this book, safe in the knowledge that their work will provide graduate students, young researchers, and engineers with the scientific and technical know-hows to uncover the secrets of solid.

Udine, Italy

Marta Boaro  
Antonino Salvatore Aricò

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