Introduction

In a time of environmental crisis, with the future of our energy sources still questionable, the awareness and concern of global society is increasing. There is a search for new technological solutions to reduce our ecological footprint and decrease our dependence on hydrocarbons. Over the last decade, hydrogen and fuel cell technologies have emerged as a potential solution, a means of transition to a more sustainable economy that has stimulated expectations as well as debate in the scientific and political community.

On the one hand, a possible transition to a 'hydrogen economy' appeals to the public, who are optimistic about the 'healing' properties of these technologies. On the other hand, a sceptical opinion on hydrogen and fuel cell technology has been shared by several decisionmakers, economists and scientists who consider the 'hydrogen economy' as a sea change in our energy infrastructure, with unclear and uncertain societal and environmental results.

Despite such divergent reactions, the last fifteen years can be considered as a watershed period for the hydrogen and fuel cell industry. Several countries have begun to develop public policies, legislation and R&D plans to sustain and promote the diffusion of these technologies in both transportation and stationary contexts (McDowall and Eames, 2006; Solomon and Banerjee, 2006). Many energy companies, in collaboration with local officials, have been actively building hydrogen infrastructure. For example, according to *Fuel Cell Today* (Huleatt-James, 2008), around 200 hydrogen refuelling stations are expected by the end of 2008, compared with close to 50 in 2003. Many large-scale projects have been launched around the world by governments in partnership with industry and NGOs, with the goal of improving technological efficiency and bridging the gap with the market. Moreover, from the mid-nineties there has been an impressive increase in patent applications focused on fuel cell technology worldwide and a steady growth in strategic alliances among industrial firms (Pogutz, Migliavacca and Russo, Chapter 5 in this book). Finally, although mass markets for these solutions are yet to come, some niche market applications – auxiliary power units (APU) for transportation, fork-lifts, and back-up solutions – seem very close to commercialization, opening up many new competitive opportunities.

In other words, hydrogen and fuel cells are lively and dynamic technologies, an intriguing and unique milieu through which to realize technological change, industry formation and innovative strategies.

GOAL OF THE BOOK

This book represents the first attempt to explore hydrogen and fuel cells from the solid theoretical perspectives of technology and innovation management. It does not simply describe what is going on in the field of hydrogen and its complementary technologies such as fuel cells, but attempts to discuss a specific phase of technological change that has been so far neglected in literature: the introductory or formative phase. While most studies and approaches observe technological and industrial dynamics in their developmental or mature stage, this work focuses on the uncertainty of the innovative processes in the early phase of a new technological trajectory or innovation system. Moreover, there is an in-depth examination of R&D and commercialization strategies for new technological solutions, from the perspective of innovation management. In other words, we explore how firms attempt to align technological and market opportunities, trying to overcome barriers and difficulties in order to diffuse new and potentially disruptive innovations.

Empirically, we focus on the case of hydrogen and fuel cell technologies.

For many centuries hydrogen has fascinated scientists (for example, Paracelsus, Boyle, Cavendish, Lavoisier) and novelists (Verne), because it is the most abundant element in the universe; it is odourless, tasteless, nontoxic, and when burned it generates energy producing almost no exhaust, with water as its only by-product. At the same time, a key characteristic of this gas is that it is not a primary source of energy, but a carrier that needs to be produced and manufactured from other sources.

Moreover, fuel cell technologies are as old as the middle of the nineteenth century. They were invented in 1839 by Sir Willam R. Groove, an English lawyer and scientist, but only since the 1990s have they received extensive attention as an agent of environmental improvement. These features, combined with rising concerns over global warming and the degradation of resources and energy supply, have reawakened interest in these potentially revolutionary technologies (Hall and Kerr, 2003).

Fuel cells are electrochemical devices that produce energy through chemical reactions by combining oxygen from air and a fuel such as hydrogen. They operate the same way as a battery, but they continue to generate electricity as long as they are supplied with fuel. Compared to internal-combustion engines, they are highly efficient; finally, they

are flexible and modular, allowing high performances through different system sizes (Lipman et al., 2004). An increasing number of young technology-based firms have therefore been established in this field since the early nineties, attracting many investors and venture capitalists, despite the high-risk level and long-term paybacks. Hydrogen and fuel cells are interrelated and complementary technologies, a realistic alternative to the dominant carbon-based energy system in many applications: large-scale and distributed energy production; transportation in trains, cars, buses and ships; and consumer appliances and products. This book investigates these different contexts and how hydrogen and fuel cells can enhance them.

Finally, this work anticipates the role hydrogen and fuel cell technologies can play in moving the world to greater sustainability. The worldwide demand for energy is rapidly increasing, as an effect of the rise of new economies in China, India, Russia and Brazil, among other countries. At the same time, environmental problems like global warming seem deeply related to the greenhouse gas emissions generated from the excessive use of fossil fuels in energy production, transportation and manufacturing activities (IPCC, 2007). The twentieth century was largely dominated by a monoculture of hydrocarbons, either as a source or as an energy carrier. We know that environmental degradation both at the global (for example, climate change) and local levels (for example, air pollution in many cities and regions) depends very much on this monoculture. The road toward sustainability calls for a diversification of energy sources. Hydrogen and complementary solutions like fuel cells represent a chance for such variety, acting as 'enabling technologies' for renewable energies and other carriers such as electricity.

THE EUROPEAN HYDROGEN AND FUEL CELL BUSINESS OBSERVATORY

This book is the first concrete product designed and realized by the European Hydrogen and Fuel Cells Business Observatory (EHFBO).

The EHFBO was launched in 2004 by Bocconi University, Milan, Italy, with the collaboration of a group of leading European universities, business schools and research centres. Its goal is to observe, analyse and comment and publish on developments within the industries related to hydrogen and fuel cell technologies. Its mission is to support government, industry, financial investors and academia in the development and implementation of policies, strategies and activities relevant to the sustainable business development of hydrogen and fuel cell technologies.

The Observatory monitors the dynamics of hydrogen and fuel cell industries through independent research, merging different competencies and skills from economic and managerial perspectives with technological and scientific expertise. Four main activities can be identified:

1. Knowledge creation, in terms of identification, collection and monitoring of information and data related to the hydrogen and fuel cell technology industries;
2. Independent guidance, through a continuous review of existing public policies and financial and market tools to foster innovation (benchmarking of best practices, dynamic tracking of policy frameworks, patent applications, role of complementary players such as financial markets and institutions);
3. Provision of content, through networking activities, research and surveys at the European and international levels;
4. External awareness. Contribution to the ongoing debate on sustainable development, global warming and resource scarcity; mainstreaming the positive impact of these new technologies at the regional, national and international levels.

The scope of the EHFBO goes beyond traditional industry observatories. First, fuel cells and hydrogen may have different potential applications, which suggests that the EHFBO activities should cover a large set of industries (such as oil, automotive, electronics, heating, energy). Second, products and services relying on hydrogen and fuel cells are in their early stage of development. As a consequence, tools and data are yet to be developed. The EHFBO seeks to develop such tools and databases in order to structure emerging knowledge, while encouraging research and innovative ideas and optimizing their diffusion to academic, business and political communities.

Beginning with these goals and innovations, a peer-to-peer network of scholars has been established. Among the organizations that have been part of this network from its inception, we count Cass Business School, London, UK; Fraunhofer Institut, Munich, Germany; Cardiff Business School, Wales, UK; Imperial College, London, UK; St Gallen University, St Gallen, Switzerland; CERAM Sophia Antipolis, Nice, France; Lund University, Lund, Sweden. From start up to now, other researchers from institutions all over the world have been contacted, informed and involved in the project.

The EHFBO was officially launched on 14 December 2004, during the Hy-Net Workshop on 'Socio-Economic Aspects of Introducing Hydrogen Energy at Large Scale in Europe'. The proposal was officially

adopted by the Initiative Group Financing and Business Development (IGFBD) of the European Hydrogen and Fuel Cells Platform (HFP) and has been included in the HFP Document 'Implementation plan – Status 2006'.

In 2007, we invited a group of colleagues involved in the EHFBO to contribute to a new book on hydrogen and fuel cell technologies, bringing together the many different theoretical approaches – from macro to micro, cross-cutting different fields and disciplines – around three key concepts: innovation, markets and sustainability. We started a wide-ranging consultation process within the EHFBO and collected valuable suggestions on how to improve the structure of the book, topics to be tackled and new perspectives to add. Moreover, we opened the project to new partners from outside Europe, who provided a more comprehensive and international perspective to this text.

Finally, in March 2008 we organized the third Workshop of the EHFBO, 'Innovation, Markets and Sustainable Energy: The Challenge of Hydrogen and Fuel Cells', at Bocconi University, where many articles in this book were presented and discussed with leading scholars and recognized experts, such as Frano Barbir, UNIDO – International Centre for Hydrogen Energy Technologies, and Lynn Mytelka, United Nations University-Maastricht Economic Research Institute of Innovation and Technology (UNU-MERIT).

OUTLINE OF THE BOOK

The book is organized into three main parts, with Part IV concluding, and includes contributions from Europe, US and Japan. Part I proposes an overview of hydrogen and fuel cell technologies, discussing the role of these technologies in the transition toward a more sustainable energy and transport system, their potential impact on dominant technologies and existing industries and strategies to develop the hydrogen infrastructure. Giorgio Simbolotti opens the text with Chapter 1 by investigating the role of hydrogen and fuel cells in our energy future, hence defining the scope and field of the whole work. Simbolotti explores the main reasons that led to the search for new, low-emissions energy technologies, focusing on topics such as global warming and climate change. The potential benefit of hydrogen and fuel cell technologies, and barriers to their development and costs are analysed in depth, based on expectations from 'major conventional hydrogen and fuel cell technologies, which are now being developed' (Simbolotti, Chapter 1 in this text). He argues that hydrogen and fuel cells may play a significant role in our energy future if CO_2 reduction

targets become effective and if relevant technological improvements are achieved along the whole hydrogen value chain.

In Chapter 2, Marcello Contestabile investigates the contribution of hydrogen and fuel cells to road-transport sustainability. In this case attention is directed to greenhouse gas (GHG) emissions reduction policies, exploring alternative scenarios based on 'well-to-wheel' energy use and selected GHG emissions pathways. Contestabile reminds us of the importance of the institutional framework as a driver of change, exploring the main EU regulations relevant to hydrogen and other alternative fuels.

In Chapter 3 Paul Harborne, Chris Hendry and James Brown move the discussion to the problems of developing and commercializing radical new technologies, introducing the reader to the technological innovation theory and to Christensen's (1997) 'innovators dilemma' model. They explore whether fuel cells are a disruptive innovation on the basis of a three-year study of firms developing these technologies along the whole supply chain in the automotive industry.

Martin Wietschel, Philipp Seydel and Michael Ball in Chapter 4 tackle another topic central to the challenge of a more sustainable energy system centred around hydrogen: the build-up of the hydrogen infrastructure. The authors investigate the numerous conditions that influence the development of the hydrogen supply, and argue that hydrogen use will probably proliferate in densely populated urban environments with favourable support policies, and then gradually expand into rural areas. Part I concludes with Chapter 5 analysing the dynamics of the fuel cell industry. Stefano Pogutz, Angeloantonio Russo and Paolo Migliavacca, on the basis of a large database developed by SPACE, Bocconi University, explore the shaping of this emerging industry over a ten-year period, from a network perspective and studying the formation of alliances between firms along the fuel cell supply chain.

Part II investigates the process of technological innovation and market diffusion according to several managerial approaches. In Chapter 6 Ludovic Dibiaggio and Maryam Nasiriyar examine the rate and the dimensions of technological advances in the fuel cell industry through a ten year (1997–2007) patent-data analysis. The authors provide a historical, descriptive analysis of innovative activities and describe the knowledge environment in which firms operate. They conclude that fuel cell innovative activities have grown over the past ten years and have increasingly incorporated specialized and complementary bodies of knowledge.

Clodia Vurro and Angeloantonio Russo in Chapter 7 look inside the fuel cell industry, exploring firms' innovation strategies. Building on the existing literature on organizational learning processes, the authors

investigate how companies manage ambidexterity, balancing external exploration and internal exploitation, and analyse the beneficial effect of this strategy on innovation performance. Vurro and Russo find that firms in the fuel cell industry are not pursuing ambidexterity: companies that focus on internal R&D are not taking into due account the importance of balancing such orientation with external development. They explain these results in terms of the emerging stage of development of the fuel cell industry, where no dominant design has yet been consolidated.

Chapter 8, by Rolf Wüstenhagen, Robert Wuebker, Mary Jean Bürer and Dale Goddard, focuses on the role of investors as actors who play a key role in the introduction and diffusion of breakthrough innovation. In particular, in the area of venture capital, they argue that investment decisions are likely to be subject to behavioural effects and the influence of expectation dynamics. The authors empirically investigate the fuel cell industry by analysing investments over a ten-year period (1997–2007). They conclude that this technology is an example of how such expectation dynamics unfold, 'resulting in a hype cycle of exuberance followed by austerity' (Wüstenhagen et al., Chapter 8 in this book).

Paul Nieuwenhuis's contribution, Chapter 9, returns to the problem of conditions and obstacles to fuel cell market introduction in the transportation sector. He briefly examines the story of the hydrogen car and discusses the strategies that firms in the automotive industry are implementing to face the challenge of diffusing this technology. Finally, some reflections on the role of new economies – such as in Asian countries – in taking the leadership for new low-carbon technologies are offered.

In Chapter 10, the last chapter of this part of the book, Paolo Agnolucci looks at niche, or early, markets, where fuel cell technologies are finding increasing application due to their power density, operational potential and low environmental impact. Portable electronics, auxiliary power units, and other specialized applications such as those in fork-lifts, trucks and drivetrains, represent early options for the large-scale commercialization of fuel cells. These applications are described in this chapter with details on the current status of development and commercial maturity.

In Part III the perspective is policy-oriented, investigating the main policies and initiatives aiming to reduce system uncertainty and complexity through coordination and stabilization. In Chapter 11 Stian Nygaard and Annika Rikne use the framework of Technological Systems (Carlsson and Stankiewicz, 1991) to analyse the EU strategy of hydrogen and fuel cells development and commercialization. They investigate the role of technology platforms as key tools in emerging technological fields, which

support the market-introduction phase, thus providing a crucial alignment between actors. The authors look at the European Hydrogen and Fuel Cell Technology Platform (HFP), established to facilitate and accelerate the development and deployment of a cost-competitive, world-class European hydrogen and fuel cell industry. Moreover, they address the question of private–public partnership, exploring the launch of the European Joint Technology Initiative for fuel cells and hydrogen.

Clovis Zapata offers a different perspective on public–private collaborations in Chapter 12, looking at the US national hydrogen policy. He argues that the use of partnerships has been a trademark of the development of hydrogen and fuel cells in the United States, allowing the public demonstration of the technology and the creation of important synergies among the actors involved in the innovation process.

In Chapter 13, the final chapter in Part III, Yuko Harayama, Philippe Larrue and Kuniaki Honda analyse the state of the art of public policies and private initiatives in Japan, one of the most advanced countries dealing with hydrogen and fuel cell technologies. In more detail, their study analyses the changing institutional framework in Japan that supports the development and commercialization of strategic technologies, with a particular focus on fuel cell technology.

The conclusion of the book, Part IV Chapter 14, by Marieke Reijalt, provides perspectives on the principal initiatives and demonstration projects implemented around Europe at the regional level. Moreover, she proposes a vision for the future, when hydrogen and fuel cell technologies will play a crucial role towards a more sustainable future.

CONCLUSIONS AND ACKNOWLEDGMENTS

This book is addressed to academics, scholars, researchers, and doctoral and masters students in the fields of innovation strategies, technology policies, strategy and management, sustainability and environmental innovation, and energy policies. Moreover the book offers a new perspective on fuel cells and hydrogen technologies that can be of great interest, to both researchers and scholars with a technical background (such as engineers, physicists and chemists), and to practitioners in the hydrogen and fuel cell industries, and in the energy field at large. To sum up, we expect this text to become an authoritative reference in the field of 'hydrogen economy' at large.

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