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Book Review

HYDROGEN AS A FUTURE ENERGY CARRIER

Andreas Züttel, Andreas Borgschulte, Louis Schlapbach (Eds.)

WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, GERMANY
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The book *Hydrogen as a Future Energy Carrier* contains 8 chapters written by specialists into different energy fields and is focused on four large areas: (1) hydrogen as a fuel, (2) hydrogen production and storage, (3) hydrogen functionalized materials and (4) hydrogen applications, especially as fuel cells, internal combustion engines and space applications.

According to what is declared into the preface written by the editors, "this book can serve as a basis for future research, and is a comprehensive overview of the basic knowledge about hydrogen and the opinions about the potential and future development of hydrogen science and technology".

Energy is essential for humanity existence and development. No matter how much fossil fuel is left and who consumes most of it one of the main strategic objectives is to develop a world sustainable energy economy for the future. Today most of our energy demand is covered by energy carriers. Therefore, a synthetic energy carrier is needed. At present, the only renewable energy carrier that can be synthesized efficiently without materials limitations and in real-time is hydrogen (e.g. electrolysis of water using a renewable energy source - solar energy). Carbon has to be avoided in future energy carriers because the burning of carbon results in a massive release of greenhouse gas CO_2 into the atmosphere. Furthermore, the combustion of hydrogen leads to the release of water to the atmosphere and the cycle is closed naturally. If the future society is able to operate fusion reactors and produce heat and electricity from this nearly unlimited energy source an energy carrier like hydrogen will be needed in order to store and transport the energy.

The primary focus of this book is the description of the technology and science of the hydrogen cycle, including hydrogen production, hydrogen storage and hydrogen conversion. The oldest hydrogen-based application is nearly 200 years old and thus the book contains an interesting survey of the hydrogen history.

All the authors of this book are from different high industrialized world countries: Switzerland, Germany, Denmark, The Netherlands, Sweden, USA, Japan, United Kingdom, and R.R. China. Thus, scientists and education staff have conquered a leading position worldwide in many areas of hydrogen energy carriers, for example in electrolysis, combustion of hydrogen together with oxygen when the energy is released as heat and work leaving water or steam into the atmospheric emissions. The hydrogen cycle is closed.

The first chapter is an introduction written by Andreas Züttel that synthetically presents the technical and economic challenge of hydrogen as a future energy carrier.

The chapter 2 "*History of Hydrogen*", authors: Andreas Züttel, Louis Schlapbach, and Andreas Borgschulte, is devoted to an outline of the history of hydrogen and relevant events which coined the overstated concerns about the safety of hydrogen (timeline of the history of hydrogen, hydrogen in transportation, the Hindenburg and challenger disasters).

In order to underline the need for a new energy strategy, chapter 3 is a accurate analysis of the world's energy status and the currently used fossil fuels. The authors of this chapter, Sonia Studer, Samuel Stucki, John D. Speight, are discussing topics as advantages and uses of fossil fuels, formation and composition of fossil fuels, global reserves and production, environmental impact, future trends, the carbon cycle and biomass energy, hydrogen cycle (replacing the fossil fuel/carbon cycles with hydrogen, key elements of the hydrogen cycle, the centrality of water, other cycles active in the global environment, the present hydrogen scenario), exploiting the hydrogen cycle for energy production:

hydrogen production (non-renewable production methods for hydrogen, renewable processes for hydrogen production, transmission, distribution and storage of hydrogen, conversion of hydrogen to energy, implementation of the hydrogen cycle; technical issues etc.). The discussions reflect the various opinions on this subject, in particular how a sustainable future should be developed. Hydrogen is, apart from its use as an energy carrier, one of the most versatile elements and is frequently taken as a physical model system. Therefore, chapter 4 written by Andreas Züttel, Andreas Borgschulte, Louis Schlapbach, Ib Choekendorff, and Seijirau Suda addresses the properties of hydrogen, ranging from the gas over its various chemical states to interactions of hydrogen with matter (e.g. hydrogen isotopes, hydrogen molecule, physical properties, chemical properties and diffusion, ignition and detonation performance, interaction of hydrogen with solid surfaces, catalysis of hydrogen dissociation and recombination, the four states of hydrogen and their characteristics and properties, surface engineering of hydrides).

Chapter 5 "*Hydrogen Production*" (authors: Andreas Borgschulte, Andreas Züttel, and Ursula Wittstadt) presents the main aspects of hydrogen production by electrolysis. Most commercial electrolysers are based on the principle of alkaline electrolysis, but solid polymers are also used as an electrolyte. Units with a hydrogen production of litters to several 10.000 cubic meters per hour are available. But, only a very small percentage (3%) of the world's hydrogen is produced by electrolysis. Even if hydrogen is used as a chemical raw material rather than as energy carrier today, this might change in the future. Electrolysis using energy from renewable sources might become a part of tomorrow's energy supply chain.

Information on *Hydrogen Storage* in molecular form into high pressure gas cylinders, or in liquid form into liquid storage vessels are synthesized into chapter 6, written by 12 author-specialists, together with main topics on hydrogen physical adsorption (physisorption), chemical adsorption (chemisorption), measuring techniques (e.g., volumetry-Sievert's method, thermal desorption spectroscopy-TDS, thermogravimetry, electrochemical method, etc.), storage in different material types such as carbon materials, zeolites, metal-organic frameworks-MOFs, metal hydrides, tetrahydroborates as a non-transition metal hydrides, complex hydrides, storage in organic hydrides, indirect hydrogen storage via metals and complexes using exhaust water. All the authors remark that they are still searching for the best hydrogen storage material and storage system. However, almost all materials and systems to be investigated in the near future will face various difficulties in their technological and engineering steps with regard to mass production, cost effectiveness, safety and handling measures.

The field of potential applications of hydrogen has developed enormously over the last ten years. Some of these applications are described in chapters 7 and 8.

Chapter 7 emphasizes thin film applications, while chapter 8 concentrates on technical realizations in mobile applications and even in space.

Thus, chapter 7 describes the remarkable optical properties of switchable metal hydride film (three generations of switchable mirrors: (1) hydrides of rare-earths and yttrium and lanthanum, (2) hydrides with Mg and MgH_2 grains, (3) complex metal hydrides). The results presented by the five author-specialists show the tremendous advantage of thin films compared to bulk metal hydrides. By using matrix samples or films with large compositional gradients it is possible to monitor optically the reaction of hydrogen with a great number of different samples evaporated on the same substrate and to explore the efficiency of new lightweight hydrogen storage materials (e.g., alanates).

The eight author-specialists of chapter 8 underline that the remarkable reversible chemistry of metal hydrides gives various devices ranging from sorption cryocoolers, to batteries, to thermal switches, to ultrapure gas sources. For over forty years hydrogen has contributed to development and implementation of space technology. Its unique combination of chemical and physical properties led to very diverse applications from being the most efficient fuel for chemical propulsion systems to providing cryogenic temperatures for specialized scientific instruments. Very strong incentives currently exist to address the fundamental issue of storing the maximum quantities of hydrogen in the smallest possible volumes – whether to enhance its propulsion capabilities or extend the size and duration of space missions.

The editors of this book have as principal goal to synthesize some encyclopaedic and technical points of view of some important specialists in the hydrogen energy field covering the most important topics and techniques needed to reach efficient energy production, storage, conversion and transportation.

This book is necessary to people working into various fields of energy and for those interested in finding new applications and actual information on new intelligent concepts on hydrogen sustainable energy, efficient and clean unlived synthetic energy carriers. The book is a real representative one into the energy education on hydrogen as energy carrier and will be a basis for researchers, scientists and even advanced students who are in process of theoretical and practical understanding of hydrogen physics and chemistry in order to be efficiently produced, well storage and consumed into environmental-friendly burning processes for useful energy generation: heat and work.

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