



Recent developments in state-of-the-art hydrogen energy technologies – Review of hydrogen storage materials

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ABSTRACT

Hydrogen energy has been assessed as a clean and renewable energy source for future energy demand. For harnessing hydrogen energy to its fullest potential, storage is a key parameter. It is well known that important hydrogen storage characteristics are operating pressure-temperature of hydrogen, hydrogen storage capacity, hydrogen absorption-desorption kinetics and heat transfer in the hydride bed. Each application needs specific properties. Every class of hydrogen storage materials has a different set of hydrogenation characteristics. Hence, it is required to understand the properties of all hydrogen storage materials. The present review is focused on the state-of-the-art hydrogen storage materials including metal hydrides, magnesium-based materials, complex hydride systems, carbonaceous materials, metal organic frameworks, perovskites and materials and processes based on artificial intelligence. In each category of materials' discovery, hydrogen storage mechanism and reaction, crystal structure and recent progress have been discussed in detail. Together with the fundamental synthesis process, latest techniques of material tailoring like nanostructuring, nanoconfinement, catalyzing, alloying and functionalization have also been discussed. Hydrogen energy research has a promising potential to replace fossil fuels from energy uses, especially from automobile sector. In this context, efforts initiated worldwide for clean hydrogen production and its use via fuel cell in vehicles is much awaiting steps towards sustainable energy demand.

Abbreviations: IEA, International Energy Agency; CEM, Clean Energy Ministerial; MI, Mission Innovation; MT, Million Tons; IRENA, International Renewable Energy Agency; AEO, Annual Energy Outlook; US-DOE, United States Department of Energy; LCOE, Levelized Cost of Electricity; SMR, Steam Methane Reforming; kWh, Kilo Watt-hour; MOF, Metal Organic Frameworks; PCTO, Fuel Cell Technologies Office; AI, Artificial Intelligence; ML, Machine Learning; SWCNT, Single Wall Carbon Nanotube; MWCNT, Multiwall Carbon Nanotube; ANI, Artificial Narrow Intelligence; AGE, Artificial General Intelligence; HSA, Hydrogen Storage Alloys; IMC, Intermetallic Compounds; Pa, Pascal; MPa, Mega Pascals; Atm, Atmosphere; BCC, Body Centered Cubic; SS, Solid Solution; Ni-MH, Nickel-Metal Hydride; P-C-T (or PCT), Pressure Composition Temperature; Wt% (or wt%), weight percentage; kJ, Kilo Joules; PEM, Proton Exchange Membrane; H₂M, Hydrogen to metal ratio; CRMM, Controlled Reactive Mechanical Milling; HRMM, High-Energy Ball Milling; NPs, Nanoparticles; PMMA, Poly(methyl methacrylate); CA, Carbon Aerogels; 2D and 3D, Two and Three Dimension; DFT, Density Functional Theory; RBC, Reactive Hydride Composite; K, Kelvin (Temperature scale); °C (or °C), Degree Celsius (Temperature scale); CC, Covalent Crystals; LOHC, Liquid Organic Hydrogen Carriers; MWCNT, Multiwall Nanotubes; GPa, GigaPascals; TM, Transition Metal; H-H, Hydrogen-Hydrogen; FCEV, Fuel Cell Electric Vehicle.

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Recent Developments In Hydrogen Technology

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Recent Developments in Power and Propulsion Applications Ashoke De, Ashwani K. Gupta, Akshai K. Runchal, Dibakar Rakshit, Abhijit Kushari, 2025-09-26 The primary focus of this contributed volume is on providing cutting edge developments in a number of critically important fields including energy combustion power propulsion environment using fossil fuels and the production and use of biofuels The availability of clean and sustainable energy is more crucial now than ever before for all areas of energy use in power mobility and propulsion In the future the energy used will only grow due to the increase in population and enhanced standards of living This book includes contributions from globally recognized specialists from various regions of the world They have provided the most recent advances in both basic and applied research on the creation of cleaner energy and its application for a variety of technologies from microscale energy conversion to supersonic and hypersonic propulsion powered by hydrocarbon fuels Clean and efficient energy conversion for various stationary and propulsion applications including hypersonic propulsion thermal management emission control and environmental issues for energy sustainability are amongst the challenges and opportunities followed for the specific applications In parallel some of the other applications include the combustion of fossil and biofuels clean energy production from low grade materials such as waste and biomass and alternative fuels via rigorous modeling and simulation with a focus on efficiency and environmental issues The present and future R D activities include specially designed technical tracks and contributions from internationally recognized technical experts that reveal different but complementary viewpoints on fuels combustion power and propulsion and air toxins The development and implementation of novel energy conversion technologies require solid fundamental

understanding as well as research and development efforts at different scales from bench to pilot to full scale We conjecture that for the foreseeable future hydrocarbon fuels will likely remain a major source of energy in all sectors of power transportation and propulsion with a slow but steady increase in renewable energy resources in the overall energy mix A multifaceted strategy is needed for the energy and environmental sustainability of all power and propulsion systems This includes creating and utilizing alternative and renewable fuels designing flexible fuel combustion systems that are simple to use with the new fuels and developing cutting edge eco friendly technologies to maximize the use of all types of gas liquid and solid fuels This book provides a wealth of knowledge as a reference for practicing engineers research engineers researchers and managers in labs and industry academic institutions graduate students and senior year undergraduates studying mechanical chemical aerospace energy and environmental and industrial engineering

Recent Developments in Hydrogen Technology - Williamson Jr KD Ed,1986

Recent Developments in Green Finance, Green Growth and Carbon Neutrality Muhammad Shahbaz,Kangyin Dong,Daniel Balsalobre-Lorente,Ayfer Gedikli,2023-08-18

Recent Developments in Green Finance Green Growth and Carbon Neutrality explains the role of green finance in transforming the global economy into a green and carbon neutral one The book explores the synergy between green growth strategy and green finance policy 2G and carbon neutrality in an economic environmental financial framework that helps readers understand how to design a feasible path toward achieving carbon neutrality through economic initiatives and financial innovations It shows how to apply the notion of green growth to organizations and illustrates the need for a theory of energy economics that estimates the benefits of a low carbon transition and carbon neutrality Sections include historical background relevant literature necessary to understand topics the notions of green finance green growth and carbon neutrality from an economic perspective Other sections cover models and methods of carbon neutrality assessment the nexus between carbon neutrality and economic development green growth and financial development green finance and green energy exploration and consumption and more Two chapters specifically focused on UN SDGs 7 and 13 round out the book and it concludes with a final section that gathers and integrates the concepts discussed throughout the book Uses green finance and green growth to develop a framework for achieving a carbon neutral society Brings together current knowledge in this field of research then goes further to explain relevant concepts and the theoretical and empirical relationship between carbon neutrality green growth and green finance Includes two chapters dedicated to a discussion of the United Nations Sustainable Development Goals 7 and 13 which underpin this book

Recent Developments in Fusion Energy Research United States. Congress. House. Committee on Science, Space, and Technology,1989

Aviation Law: Recent Developments In Aviation Laws Gazala Noor,2024-09-17

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Recent Development in Energy Conversion Systems Sunday Olayinka Oyedepo, Fidelis Ibiang Abam, Olusegun David Samuel, Oluseyi Olanrewaju Ajayi, Abimbola Patricia Popoola, Diana-Andra Borca-Tasciuc, 2024-03-15 In this industrial and technological age energy plays a principal role in sustainable development This is connected to issues regarding availability production processes utilization and environmental impact Due to the increased rate of population growth the energy demand in the entire world is getting to the level that it may not be sustained in the nearest future if drastic action is not taken to address the situation especially from research and development perspectives None of the millennium development goals MDGs can be completed without considerable improvements in the quality and quantity of energy services in developing countries according to the United Nations Development Programme UNDP Based on this fact UNDP is making efforts especially in developing countries to ensure that people have access to sustainable sources of clean reliable and affordable energy since every aspect of human development is highly impacted by this vital resource

Advances in Refining Catalysis Deniz Uner, 2017-03-16 To meet changing market demands that have stringent emission standards and to ensure proper performance in refinery units evaluation of novel catalyst designs and results from material characterization and testing of catalysts are of crucial importance for refiners as well as for catalyst manufacturers This book highlights recent developments in the application of refinery catalysts in selected units such as fluid catalytic cracking FCC hydrogen production for hydroprocessing units hydrotreating hydrocracking and sustainable processing of biomass into biofuels

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