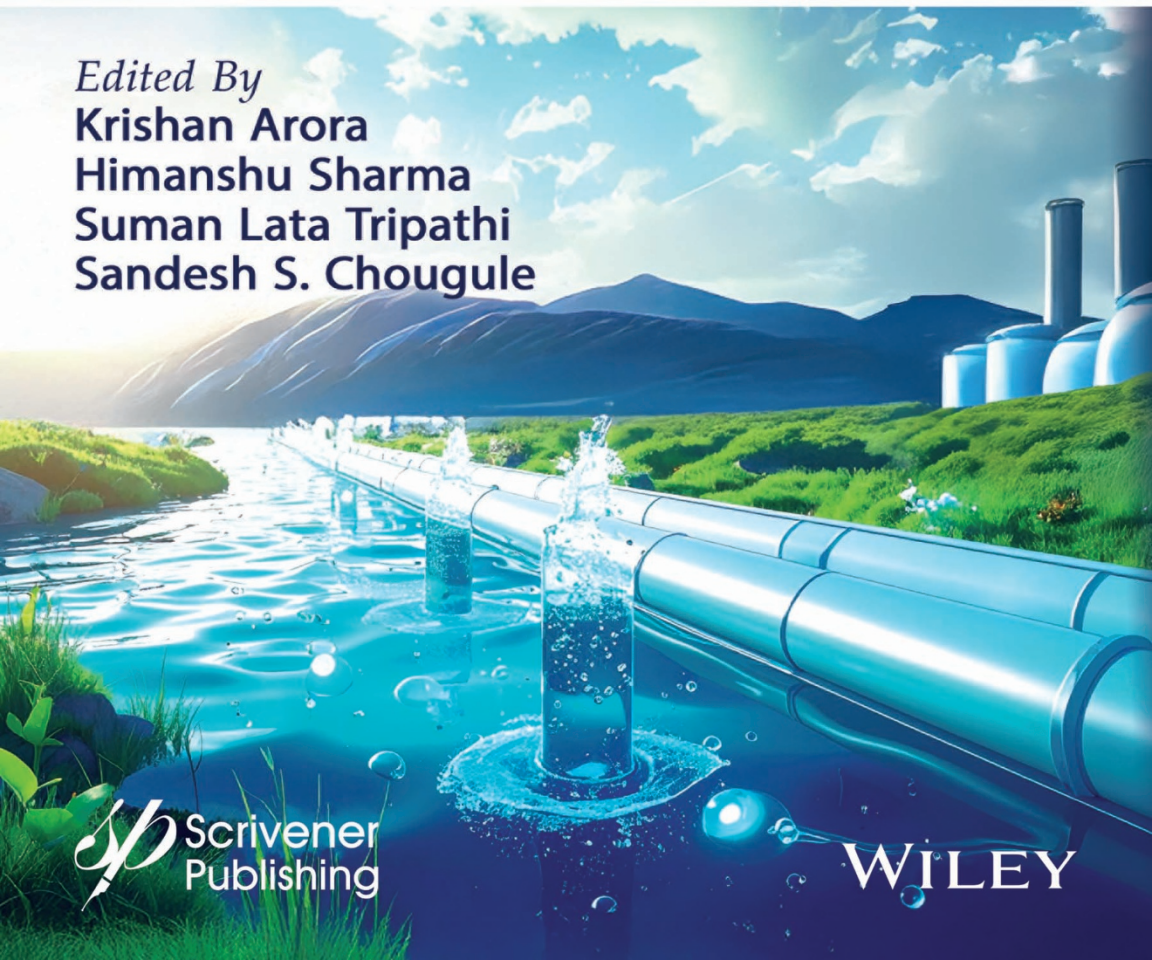
HYDROGEN ENERGY SYSTEMS

ADVANCING SUSTAINABLE POWER SOLUTIONS

Edited By
Krishan Arora
Himanshu Sharma
Suman Lata Tripathi
Sandesh S. Chougule



Scrivener Publishing

WILEY

Hydrogen Energy Systems

Scrivener Publishing
100 Cummings Center, Suite 541J
Beverly, MA 01915-6106

Publishers at Scrivener
Martin Scrivener (martin@scrivenerpublishing.com)
Phillip Carmical (pcarmical@scrivenerpublishing.com)

Hydrogen Energy Systems

Advancing Sustainable Power Solutions

Edited by

Krishan Arora

Himanshu Sharma

Suman Lata Tripathi

and

Sandesh S. Chougule

WILEY

This edition first published 2026 by John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA and Scrivener Publishing LLC, 100 Cummings Center, Suite 541J, Beverly, MA 01915, USA

For more information about Scrivener publications please visit www.scrivenerpublishing.com.

Wiley Global Headquarters
111 River Street, Hoboken, NJ 07030, USA

For details of our global editorial offices, customer services, and more information about Wiley products visit us at www.wiley.com.

The manufacturer's authorized representative according to the EU General Product Safety Regulation is Wiley-VCH GmbH, Boschstr. 12, 69469 Weinheim, Germany, e-mail: Product_Safety@wiley.com.

Limit of Liability/Disclaimer of Warranty
While the publisher and authors have used their best efforts in preparing this work, they make no representations or warranties with respect to the accuracy or completeness of the contents of this work and specifically disclaim all warranties, including without limitation any implied warranties of merchantability or fitness for a particular purpose. No warranty may be created or extended by sales representatives, written sales materials, or promotional statements for this work. The fact that an organization, website, or product is referred to in this work as a citation and/or potential source of further information does not mean that the publisher and authors endorse the information or services the organization, website, or product may provide or recommendations it may make. This work is sold with the understanding that the publisher is not engaged in rendering professional services. The advice and strategies contained herein may not be suitable for your situation. You should consult with a specialist where appropriate. Neither the publisher nor authors shall be liable for any loss of profit or any other commercial damages, including but not limited to special, incidental, consequential, or other damages. Further, readers should be aware that websites listed in this work may have changed or disappeared between when this work was written and when it is read.

AI disclosure statement: The author confirms that no artificial intelligence (AI)-generated content or AI-assisted writing tools were used in the preparation of this chapter (including summaries and the abstract). All text, analysis, and conclusions are the result of the author's original work.

Library of Congress Cataloging-in-Publication Data

ISBN 9781394358373

Front cover images supplied by Pixabay.com
Cover design by Russell Richardson

Set in size of 11pt and Minion Pro by Manila Typesetting Company, Makati, Philippines

Printed in the USA

10 9 8 7 6 5 4 3 2 1

Contents

List of Contributors

Brijlal Mallik
Department of Management, Brainware University, Kolkata, India

Manish Kumar
Department of Management, Brainware University, Kolkata, India

Yawei Lu
College of Safety Science and Engineering, Nanjing Tech University, Nanjing, China

Pravin Kumar
Department of Management, Brainware University, Kolkata, India

Dev Kumar Mondal
Department of Management, Brainware University, Kolkata, India

Michael L. Johns
Chemical and Process Engineering, University of Western Australia, Australia

Shivangi Kashyap
Department of Finance, Brainware University, Kolkata , India

Vivek Hamal
Department of Management, Brainware University, Kolkata, India

Krishnendu Ghosh
Department of Commerce, Brainware University, Kolkata, India

Shrish Bajpai
Electronics & Communication Engineering Department, Faculty of Engineering & Information Technology, Integral University, Lucknow, Uttar Pradesh, India

Divya Sharma
Electronics & Communication Engineering Department, Institute of Engineering and Technology, Lucknow, Uttar Pradesh, India

Jeya Daisy
Kumaraguru College of Technology, Coimbatore Tamil Nadu, India

Dr. Sarat Kumar Sahoo
Department of Electrical Engineering, Parala Maharaja Engineering College, Berhampur, Odisha, India

Durgadevi Samantara
Department of Electrical Engineering, Parala Maharaja Engineering College, Berhampur, Odisha, India

Nipon Ketjoy, Dr.-Ing
School of Renewable Energy and Smart Grid Technology (SGtech), Naresuan University, Phitsanulok, Thailand

Suman Lata Tripathi
Department of Electronics and Telecommunication Engineering, Symbiosis Institute of Technology, Symbiosis International (Deemed University), Pune, India

Abhishek Kumar
School of Electronics and Electrical Engineering, Lovely Professional University, Punjab, India

Harpreet Singh Bedi
School of Electronics and Electrical Engineering, Lovely Professional University, Punjab, India

Ranjit Kumar Bindal
Department of Electrical Engineering, Chandigarh University, Mohali, India

Prashant Kumar
Electrical Engineering Department, Chandigarh University, India

Manish
Electrical Engineering (Electric Vehicle), Chandigarh University, Mohali, India

Charanjot Singh
Electrical Engineering (Electric Vehicle), Chandigarh University, Mohali, India

Sahil Bhardwaj
Instrumentation Engineering, Panjab University Chandigarh, India

Mohanraj K. S.
Department of Mechanical Engineering, Erode Sengunthar Engineering College, Erode, India

Sivasankari S.
Department of Information Technology, Erode Sengunthar Engineering College, Erode, India

A. Arun Negemiya
Department of Aerospace Engineering, SNS College of Technology, Coimbatore, India

Dhivya Priya E. L.
Department of Electronics and Communication Engineering, Erode Sengunthar Engineering College, Erode, India

V. Vaithiyanathan
QA/QC- Engineer, Ras Laffan Petrochemicals Project (RLPP), Polyethylene Plant, Gulf Asia

Aditya
Computer Science and Engineering, Neelkant Institute of Technology, Meerut, India

Gaurav Kumar
Mechanical Engineering, Vidya College of Engineering, Meerut, India

Vishal Kohli
Computer Science and Engineering, Neelkant Institute of Technology, Meerut, India

Krishan Arora
Electronics & Electrical Engineering, Lovely Professional University, Punjab, India

D. Santhanamary Sasireka
Department of Physics, Velammal Engineering College, Chennai, Tamil Nadu, India

T. A. Revathy
Department of Physics, Velammal Engineering College, Chennai, Tamil Nadu, India

S. Shahil Kirupavathy
Department of Physics, Velammal Engineering College, Chennai, Tamil Nadu, India

Abdul Razak Mohamed Sikkander
Department of Chemistry, Velammal Engineering College, Chennai, Tamil Nadu, India

Devanshi Srivastava
Department of Chemical Engineering, Harcourt Butler Technical University Kanpur, Uttar Pradesh, India

Adarsh Kumar Arya
Department of Chemical Engineering, Harcourt Butler Technical University Kanpur, Uttar Pradesh, India

Tousif Mzili
Department of Computer Science, Faculty of Science, Chouaib Doukkali University EI Jadida, Morocco

Nibedita Nath
Department of Chemistry, D.S Degree College, Laida, Sambalpur, Odisha, India

Subhendu Chakroborty
School of Applied Sciences, Chandigarh University, Uttar Pradesh, India

Monica Mehrotra
School of Engineering, Chandigarh University, Uttar Pradesh, India

Rintu Kumar
Department of Mechanical Engineering, IES Institute of Technology & Management, IES University, Bhopal Madhya Pradesh, India

Sulabh Sachan
Department of Electrical Engineering, University of South-Eastern Norway

Mohammad Danish
Department of Civil Engineering, Faculty of Engineering & Information Technology, Integral University, Lucknow, Uttar Pradesh, India

Mohd Sadat
Department of Civil Engineering, Faculty of Engineering & Information Technology, Integral University, Lucknow, Uttar Pradesh, India

Syed Aqeel Ahmad
Department of Civil Engineering, Faculty of Engineering & Information Technology, Integral University, Lucknow, Uttar Pradesh, India

Mehmet Ali Silgu
Department of Civil Engineering, Bartin University, Bartin, Turkey

M. Divya Bharathi
Department of Physics, Easwari Engineering College, Chennai, India

J. Arumugam
Department of Physics, Velammal Engineering College (Autonomous), Chennai, India

M. Jayachandiran
Department of Physics, Velammal Engineering College (Autonomous), Chennai, India

A. Dhayal Raj
Department of Physics, Sacred Heart College (Autonomous), Tirupattur, India

D. Anitha Jennifer
Department of Physics, Velammal Engineering College, Chennai, Tamil Nadu, India

S. Shahil Kirupavathy
Department of Physics, Velammal Engineering College, Chennai, Tamil Nadu, India

T. A. Revathy
Department of Physics, Velammal Engineering College, Chennai, Tamil Nadu, India

Preface

The growing global demand for clean and sustainable energy has placed hydrogen at the forefront of next-generation power solutions. As the world transitions from fossil fuels to renewable energy, hydrogen has emerged as a versatile and promising energy carrier with the potential to decarbonize various sectors, including transportation, industry, and power generation. This book, *Hydrogen Energy Systems: Advancing Sustainable Power Solutions*, provides a comprehensive exploration of the fundamental principles, technologies, and applications of hydrogen energy. It is designed to serve as a valuable resource for researchers, engineers, policymakers, and students who are keen to understand the role of hydrogen in the global energy landscape.

The chapters within this book cover key aspects of hydrogen energy systems, including production methods, storage solutions, fuel cell technologies, and integration with renewable energy sources. Additionally, the environmental, economic, and policy dimensions of hydrogen energy are discussed to provide a holistic perspective on its potential and challenges.

Our objective in compiling this book is to bridge the knowledge gap between theoretical research and practical implementation. By presenting the latest advancements in hydrogen energy, we aim to equip readers with the insights necessary to contribute to the development of sustainable and efficient hydrogen-based energy solutions.

We extend our gratitude to the researchers, industry professionals, and institutions that continue to advance the field of hydrogen energy. Their contributions and innovations are paving the way for a cleaner and more sustainable future. We hope this book serves as a valuable guide for all those invested in the evolution of hydrogen energy systems.

Author(s)
Krishan Arora
Himanshu Sharma
Suman Lata Tripathi
Sandesh S. Chougule

13

Hydrogen in Transportation

Mohammad Danish[1], Mohd Sadat[1]*, Syed Aqeel Ahmad[1] and Mehmet Ali Silgu[2]

[1]Department of Civil Engineering, Faculty of Engineering & Information Technology, Integral University, Lucknow, Uttar Pradesh, India
[2]Department of Civil Engineering, Bartin University, Bartin, Turkey

Abstract

The transportation sector is a major contributor to global emissions, necessitating a shift toward sustainable energy sources. Hydrogen has emerged as a promising alternative fuel, offering zero emissions and high energy efficiency. This paper explores the role of hydrogen in transportation, focusing on its adoption in freight transport, business models for hydrogen producers and refueling station owners, and policy frameworks supporting its integration. Various studies highlight strategies for hydrogen deployment in different regions, including China, Sweden, and the Nordic countries, with an emphasis on decarbonization, market acceptance, and infrastructure development. Key challenges such as hydrogen production, storage, transportation, and fuel cell advancements are also discussed. Additionally, the paper examines the economic and environmental implications of hydrogen as a transportation fuel, including the potential of green hydrogen from renewable sources and biomass-based hydrogen production. By analyzing global trends, technological advancements, and policy initiatives, this study provides insights into the feasibility of hydrogen as a sustainable transportation fuel and its role in the transition toward a low-carbon future.

***Keywords*:** Hydrogen fuel, sustainable transportation, fuel cell vehicles, hydrogen supply chain

**Corresponding author*: sadat.kh@gmail.com

Krishan Arora, Himanshu Sharma, Suman Lata Tripathi and Sandesh S. Chougule (eds.) Hydrogen Energy Systems: Advancing Sustainable Power Solutions, (275–298)

13.1 Introduction

The global imperative to decarbonize the transportation sector has positioned hydrogen as a pivotal energy carrier, offering a pathway to reduce greenhouse gas emissions and dependency on fossil fuels. The use of intelligent transportation systems has considerably reduced the emissions [36–40]. Hydrogen's versatility, high energy density, and zero-emission potential in fuel cell (FC) applications make it a cornerstone of sustainable energy strategies. However, the transition to a hydrogen-based economy faces multifaceted challenges, spanning production, storage, infrastructure, analytical precision, policy harmonization, and scalable adoption. Hydrogen has gained prominence as a clean alternative due to its high energy density, compatibility with renewable sources, and potential for zero-carbon operations. This review examines hydrogen's role across transportation modes, evaluates storage and production methodologies, and assesses policy frameworks driving its adoption. Despite technological progress, challenges such as infrastructure gaps, cost competitiveness, and supply chain limitations hinder widespread implementation. By addressing these barriers, hydrogen could revolutionize transportation, aligning with global climate goals and fostering energy security [31–35].

13.2 Literature Review

Otto *et al.* [12] investigated the feasibility of hydrogen as a zero-carbon fuel source for the transportation sector, analyzing various chemical energy carriers including ammonia, methane, and formic acid. The results indicate that the utilization of pure hydrogen—absent of any carrier—is optimally aligned with power generation applications, where substantial volumes are requisite. In the aviation sector, which poses significant challenges in terms of decarbonization, both ammonia and hydrogen demonstrate potential as feasible fuel alternatives. Furthermore, ammonia is distinguished as an effective medium for the transportation of hydrogen and the operation of container vessels. Concurrently, with regard to long-haul trucking, cryogenic or compressed hydrogen emerges as the most pragmatic option owing to its reduced volumetric requirements and the imperative for high purity.

Kurc analyzed the transition to hydrogen-driven vehicles as a plausible sustainable energy option, contrasting them with electric vehicles (EVs) and hydrogen fuel cell vehicles (HFCVs). It examines the advantages