

SAE =DGE=™
RESEARCH REPORT

**Unsettled Issues
Concerning the Use of
Fuel Cells in Electric
Ground Vehicles**

Bartłomiej Kolodziejczyk, PhD

Unsettled Issues Concerning the Use of Fuel Cells in Electric Ground Vehicles

Bartłomiej Kołodziejczyk, PhD
H2S Energy Pte Ltd.

CONTRIBUTORS

Alena Fargere, *World Energy Council*
James Carton, *Dublin City University*
Anna Trendewicz, *E.ON*
Jose Castro, *Alenia*
Ad Astra Rocket Company
Craig Knight,
Horizon Fuel Cell Technologies

Natalia Macauley, *Los Alamos National
Laboratory*
Sidarth Komini Babu, *Los Alamos National
Laboratory*
Wee-Liat Ong, *Zhejiang University*
David Dvorak, *University of Maine*
Lech Birek, *Shell Energy*





About the Publisher

SAE International® is a global association of more than 128,000 engineers and related technical experts in the aerospace, automotive, and commercial-vehicle industries. Our core competencies are lifelong learning and voluntary consensus standards development. Visit sae.org.

SAE EDGE™ Research Report Disclaimer

SAE EDGE™ Research Reports focus on topics that are dynamic, in which knowledge is incomplete, and which have yet to be standardized. They represent the collective wisdom of a group of experts and serve as a practical guide to the reader in understanding unsettled subject matter. They are not meant to provide a recommended practice or protocol. The experts engaged have contributed their own thoughts and points of view, and these are not the positions of the institutions or businesses with which they are affiliated. A professional writer has collectivized their input; there is no one contributor's perspective being advanced but rather that of a community of practitioners. SAE EDGE™ Research Reports are the property of SAE International, and SAE alone is responsible for their content.

About This Publication

SAE EDGE™ Research Reports provide state-of-the-art and state-of-industry examinations of the most significant topics in mobility engineering. SAE EDGE™ contributors are experts from research, academia, and industry, who have come together to explore and define the most critical advancements, challenges, and future direction in areas such as vehicle automation, unmanned aircraft, Internet of Things (IoT) and connectivity, cybersecurity, advanced propulsion, and advanced manufacturing.

Related Resources

SAE MOBILUS® Power/Powertrain Knowledge Hub

<https://saemobilus.sae.org/overview/>

SAE Team

Frank Menchaca, Chief Product Officer

Michael Thompson, Director, Standards, Information and Research Publications

Monica Moguira, Acquisitions Director

Jill Leonard, Product Manager

William Incinski, Managing Technical Editor

Copyright © 2020 SAE International. All rights reserved.

No part of this publication may be reproduced, stored in a retrieval system, distributed, or transmitted in any form or by any means without the prior written permission of SAE International. For permission and licensing requests, contact SAE Permissions, 400 Commonwealth Drive, Warrendale, PA 15096-0001, USA; e-mail: copyright@sae.org; phone: 724-772-4028; fax: 724-772-9765.

Printed in USA

Information contained in this work has been obtained by SAE International from sources believed to be reliable. However, neither SAE International nor its authors guarantee the accuracy or completeness of any information published herein and neither SAE International nor its authors shall be responsible for any errors, omissions, or damages arising out of the use of this information. This work is published with the understanding that SAE International and its authors are supplying information but are not attempting to render engineering or other professional services. If such services are required, the assistance of an appropriate professional should be sought.

ISSN 2640-3536

e-ISSN 2640-3544

ISBN 978-1-4606-0111-5

To purchase bulk quantities, please contact: SAE Customer Service

E-mail: CustomerService@sae.org

Phone: 877-606-7323 (inside USA and Canada)

724-776-4970 (outside USA)

Fax: 724-776-0790

Visit the SAE International Bookstore at books.sae.org

About the Series Editor



Bart Kolodziejczyk, PhD, is Chief Technology Officer of the Singapore-based H2SG Energy Pte Ltd. In his role, Kolodziejczyk develops hydrogen generation technologies and works with a number of customers throughout the Asia-Pacific region to implement hydrogen solutions in transportation, energy storage, and other industrial applications. Kolodziejczyk became interested in hydrogen power in 2009 while developing and testing fuel cell inverters for Danfoss Solar Inverter A/S. Kolodziejczyk holds a master's degree in Renewable Energy Science with focus on Fuel Cell Systems and Hydrogen awarded jointly by the University of Iceland and the University of Akureyri, as well as two PhDs in Materials Engineering from Monash University in Australia and Microelectronics from Ecole des Mines de Saint-Etienne in France. Kolodziejczyk has extensive research experience in electrochemistry, catalysis, fuel cell development, and hydrogen generation. He was a Research Fellow at Carnegie Mellon University, where he explored materials for biosensing and energy applications. Kolodziejczyk has advised the United Nations, Organisation for Economic Co-operation and Development (OECD), G20, and European Commission Council of Science, Technology, and Innovation Policy and was named one of MIT Technology Review's Innovators Under 35 for developments of new energy materials and catalysts. Kolodziejczyk has published extensively, covering electrocatalysis and hydrogen generation and its application, among other energy fields. Kolodziejczyk is a Fellow of the Royal Society of Arts, Member of the Royal Society of Chemistry, and Chartered Environmentalist.

contents

About the Series Editor

Unsettled Issues Concerning the Use of Fuel Cells in Electric Ground Vehicles 3

Introduction	4
<i>State of the Industry</i>	4
<i>Unsettled Domains in Fuel Cell Electric Vehicle Industry</i>	5
Fuel Cell Technology: Past, Present, and Future	5
<i>Fuel Cell Systems and Their Types</i>	5
<i>Fuel Cell Electric Vehicles versus Internal Combustion Engine and Battery Electric Vehicles: Technology Comparison</i>	5
<i>Technology Readiness Level</i>	6

Distinct Segments of the Global Hydrogen

Fuel Cell Vehicle Market by Vehicle Type	7
<i>Passenger Vehicles</i>	8
<i>Commercial Vehicles</i>	9
Fuel Cell Electric Buses (FCEBs)	9
Fuel Cell Electric Trucks	9
Material Handling Vehicles	10

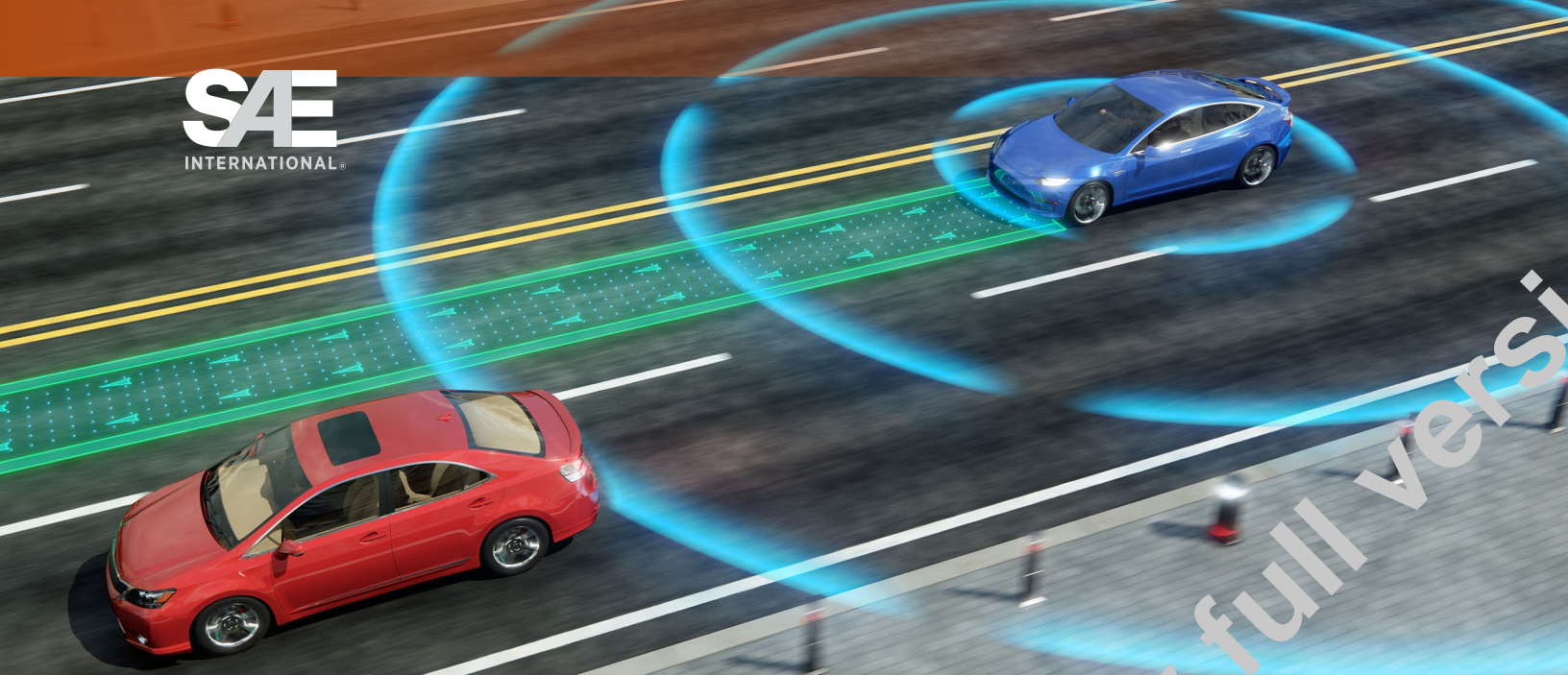
Hydrogen Availability	7
<i>Hydrogen Generation Pathways</i>	10
<i>Hydrogen Refueling Infrastructure</i>	12
<i>Understanding Hydrogen Classification</i>	13

Niche Market versus Mass Production	13
<i>Economic Drivers for Fuel Cell Vehicle Technology</i>	14
<i>Role of Learning-by-Doing and Scale Effects in Market Penetration of Fuel Cell Electric Vehicles</i>	14
<i>Demand and Subsidies as a Major Market Disruptions</i>	15
<i>Availability of Hydrogen Refueling Infrastructure</i>	15

Social Aspects of Commercial Hydrogen Rollout and Hydrogen Education	15
<i>Breaking Social Perception of Hydrogen</i>	15
<i>Developing Technological Understanding, Skills, and Maintenance Know-How</i>	16

Hydrogen Handling and Safety Aspects	17
<i>The Role of Regulations and Safety Standards</i>	18

Report Conclusions and Recommendations	19
<i>Case for Partnerships and Consolidated Implementation Approaches</i>	19
<i>Next Steps for Fuel Cell Electric Ground Vehicles</i>	21
<i>Recommendations</i>	22
<i>SAE EDGE™ Research Reports</i>	22
<i>Abbreviations/Definitions</i>	22
<i>Works Cited</i>	23
<i>Contact Information</i>	25



Unsettled Issues Concerning the Use of Fuel Cells in Electric Ground Vehicles

Abstract

Hydrogen fuel is rapidly emerging as a clean energy carrier solution that has the potential to decarbonize a variety of industries, including, or predominantly, the transportation industry. Fuel cell electric vehicles (FCEVs), which electrochemically combine stored hydrogen with atmospheric oxygen to efficiently generate electricity while producing only water vapor and small amounts of heat, are heralded to be a game-changing technology. The so-called hydrogen economy has the potential to displace traditional fossil fuel-based economy, with the transportation industry being the first mover in the hydrogen space.

Technological advances made in the last decade in the areas of hydrogen generation and fuel cell technology have enabled the current uptake of hydrogen-based solutions for vehicle applications. Reduced costs, climate change, and carbon tax mechanisms are driving many governments, manufacturers, and consumers toward hydrogen-powered vehicles. The major drawbacks of hydrogen compared to the other competing clean-energy technologies (e.g., battery power), is the high cost of hydrogen refueling and FCEVs. However, application of the economy of scale will enable further cost reduction and broad international uptake of hydrogen in automotive applications.

This Society of Automotive Engineers (SAE) EDGE™ Research Report explores the opportunities and challenges of hydrogen and fuel cell systems in the automotive industry. With the help of expert contributors, several different technological, economic, and safety aspects are considered to develop a better understanding of this emerging hydrogen-based automotive industry. While debates between proponents of battery electric vehicles (BEVs) and FCEVs continue, the current report discusses the unsettled issues in the latter technology and presents a critical overview of the hydrogen and fuel cell systems in the automotive industry. Finally, the report concludes with a series of recommendations aimed at the industry and government stakeholders for implementing and advancing hydrogen transportation projects.

NOTE: SAE EDGE™ Research Reports are intended to identify and illuminate critical issues in emerging, but still unsettled, technologies of interest to the mobility industry. The goal of SAE EDGE™ Research Reports is to stimulate discussion and work in the hope of promoting and speeding resolution of identified issues. SAE EDGE™ Research Reports are not intended to resolve the issues they identify or close any topic to further scrutiny.

**BARTLOMIEJ
KOŁODZIEJCZYK, PhD**
H2SG Energy Pte Ltd.

Contributors

Alena Fargere, *World Energy Council*
James Carton, *Dublin City University*
Anna Trendewicz, *E.ON*
Jose Castro Nieto,
Ad Astra Rocket Company
Craig Knight,
Horizon Fuel Cell Technologies
Natalia Macauley,
Los Alamos National Laboratory
Sidarth Komini Babu,
Los Alamos National Laboratory
Wee-Liat Ong, *Zhejiang University*
David Dvorak, *University of Maine*
Lech Birek, *Shell Energy*

ISSN 2640-3536