

**SUSTAINABLE  
INNOVATIONS  
IN BIOMASS  
TRANSFORMATION  
TO CHEMICALS, FUELS  
AND MATERIALS**



**SUSTAINABLE  
INNOVATIONS  
IN BIOMASS  
TRANSFORMATION  
TO CHEMICALS, FUELS  
AND MATERIALS**

**Edited by  
Nor Aishah Saidina Amin  
Amnani Shamjuddin**



[www.penerbit.utm.my](http://www.penerbit.utm.my)

2023

First Edition 2023

© **NOR AISHAH SAIDINA AMIN & AMNANI SHAMJUDDIN** 2023

Hak cipta terpelihara. Tiada dibenarkan mengeluarkan ulang mana-mana bahagian artikel, ilustrasi, dan isi kandungan buku ini dalam apa juga bentuk dan cara apa jua sama ada dengan cara elektronik, fotokopi, mekanikal, atau cara lain sebelum mendapat izin bertulis daripada Timbalan Naib Canselor (Penyelidikan & Inovasi), Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor Darul Ta'zim, Malaysia. Perundingan tertakluk kepada perkiraan royalti atau honorarium.

*All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical including photocopying, recording, or any information storage and retrieval system, without permission in writing from Deputy Vice-Chancellor (Research & Innovation), Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor Darul Ta'zim, Malaysia. Negotiation is subject to royalty or honorarium estimation.*

Editor : **NOR AISHAH SAIDINA AMIN & AMNANI SHAMJUDDIN**

Editor Penyelaras/*Acquisition Editor* : **RASYIQAH ABD RANI & NUR ALIAH ABU ZAKI**

Pereka Kulit / *Cover Designer* : **FAHAMIN ABDUL GHANI**

Diatur huruf oleh / *Typeset by* :

**NOR AISHAH SAIDINA AMIN & AMNANI SHAMJUDDIN**

Fakulti Kejuruteraan Kimia dan Kejuruteraan Tenaga

UNIVERSITI TEKNOLOGI MALAYSIA

81310 UTM Johor Bahru

Johor Darul Ta'zim, MALAYSIA

Diterbitkan di Malaysia oleh:

**PENERBIT UTM PRESS**

UNIVERSITI TEKNOLOGI MALAYSIA

81310 UTM Johor Bahru

Johor Darul Ta'zim, MALAYSIA

(PENERBIT UTM ahli MAJLIS PENERBITAN

ILMIAH MALAYSIA–MAPIM dan MABOPA

dengan no. keahlian 9101)

Dicetak di Malaysia oleh:

**JASAMAX ENTERPRISE**

No. 16, Jalan Kebudayaan 2,

Taman Universiti

81300 Skudai, Johor, MALAYSIA



Cataloguing-in-Publication Data

Perpustakaan Negara Malaysia

A catalogue record for this book is available from the

National Library of Malaysia

ISBN 978-983-52-2010-4

# Contents

<i>Contributors</i>		<i>ix</i>
<i>Preface</i>		<i>xiii</i>
<b>Chapter 1</b>	<b>Introduction to Biomass Conversion</b>	<b>1</b>
	<i>Amnani Shamjuddin, Zhashidah Husna Hassan, Nur Aainaa Syahirah Ramli, and Nor Aishah Saidina Amin</i>	
<b>Chapter 2</b>	<b>Bio-Based Alkyl Levulinate Derived from Biomass via Thermo-Catalytic Alcoholysis Process</b>	<b>59</b>
	<i>Abdull Hafidz Hassan, Muzakkir Mohammad Zainol, Mohd Asmadi, and Ahmad Rafizan Mohamad Daud</i>	
<b>Chapter 3</b>	<b>Microwave-Assisted Pyrolysis as an Advanced Technology for Biochar Production from Lignocellulosic Biomass Conversion</b>	<b>95</b>
	<i>Nur Aina Najwa Mohd Nor Azman, Mohd Asmadi, and Muzakkir Mohammad Zainol</i>	
<b>Chapter 4</b>	<b>Characteristics of Biochar from Microwave Pyrolysis of Oil Palm Shell</b>	<b>109</b>
	<i>Adekunle Moshood Abioye, Farid Nasir Ani, and Mohd Asmadi</i>	

<b>Chapter 5</b>	<b>Conversion of Lignocellulosic Biomass to Nanocellulose</b>	<b>131</b>
	<i>Ahmad Ilyas Rushdan, Mohd Nor Faiz Norrrahim, Khoo Pui San, and Abu Hassan Nordin</i>	
<b>Chapter 6</b>	<b>Carboxymethyl Cellulose Production from Empty Fruit Bunch by Ozonolysis Pre-Treatment</b>	<b>199</b>
	<i>Wan Nor Nadyaini Wan Omar, Danish Akhmal Jihat @ Ahmad, Satharobni Munandi, and Nor Aishah Saidina Amin</i>	
<b>Chapter 7</b>	<b>Catalytic Glycerol Transformation to Value Added Chemicals</b>	<b>239</b>
	<i>Zaki Yamani Zakaria, Mazura Jusoh, Muhammad Tahir, and Didi Dwi Anggoro</i>	
<b>Chapter 8</b>	<b>Co-Digestion of Palm Oil Mill Effluent and Pineapple Peel Wastes for Biogas Production</b>	<b>287</b>
	<i>Muhd Nazrul Hisham Zainal Alam, Sani Amril Samsudin, Raudhah Othman, and Mohd Johari Kamaruddin</i>	
<b>Chapter 9</b>	<b>Nanocellulose Derived from Agricultural Waste for Biomaterial Development</b>	<b>305</b>
	<i>Aryanny Nasir, Siti Pauliena Mohd Bohari, Jamarosliza Jamaluddin, and Nadia Adrus</i>	

<b>Chapter 10</b>	<b>Lignin Degradation and Total Reducing Sugar Recovery using Response Surface Methodology and Artificial Neural Network</b>	<b>329</b>
	<i>Wan Nor Nadyaini Wan Omar, Hamdya Sabrina Mohidin Yahya, Siti Nor Aishah Ismail, and Nor Aishah Saidina Amin</i>	
<b>Index</b>		<b>379</b>





# Contributors

**Abdull Hafidz Hassan** *Faculty of Chemical Engineering, College of Engineering, Universiti Teknologi MARA (UiTM), Shah Alam, Malaysia*

**Abu Hassan Nordin** *Faculty of Applied Science, Universiti Teknologi MARA (UiTM), Arau, Malaysia*

**Adekunle Moshood Abioye** *Department of Mechanical/Production Engineering, Abubakar Tafawa Balewa University, Bauchi, Nigeria*

**Ahmad Ilyas Rushdan** *Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia*

**Ahmad Rafizan Mohamad Daud** *Faculty of Chemical Engineering, College of Engineering, Universiti Teknologi MARA (UiTM), Shah Alam, Malaysia*

**Amnani Shamjuddin** *Chemical Reaction Engineering Group (CREG), Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia*

**Aryanny Nasir** *Department of Biosciences, Faculty of Science, Universiti Teknologi Malaysia, Johor Bahru, Malaysia*

**Danish Akhmal Jihat @ Ahmad** *Chemical Reaction Engineering Group (CREG), Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia*

**Didi Dwi Anggoro** *Department of Chemical Engineering, Universitas Diponegoro, Indonesia*

**Farid Nasir Ani** *Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia*

**Hamdya Sabrina Mohidin Yahya** *Chemical Reaction Engineering Group (CREG), Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia*

**Jamarosliza Jamaluddin** *Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia*

**Khoo Pui San** *Centre of Advanced Composite Materials (CACM), Universiti Teknologi Malaysia, Johor Bahru, Malaysia*

**Mazura Jusoh** *Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia*

**Mohd Asmadi** *Chemical Reaction Engineering Group (CREG), Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia*

**Mohd Johari Kamaruddin** *Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia*

**Mohd Nor Faiz Norrrahim** *Research Centre for Chemical Defence, Universiti Pertahanan Nasional Malaysia, Kuala Lumpur, Malaysia*

**Muhammad Tahir** *Department of Chemical & Petroleum, United Arab Emirates University, UAE*

**Muhd Nazrul Hisham Zainal Alam** *Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia*

**Muzakkir Mohammad Zainol** *Faculty of Chemical Engineering, College of Engineering, Universiti Teknologi MARA, Shah Alam, Malaysia*

**Nadia Adrus** *Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia*

**Nor Aishah Saidina Amin** *Chemical Reaction Engineering Group (CREG), Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia*

**Nur Aainaa Syahirah Ramli** *Quality and Environmental Assessment Unit, Malaysian Palm Oil Board (MPOB), Selangor, Malaysia*

**Nur Aina Najwa Mohd Nor Azman** *Chemical Reaction Engineering Group (CREG), Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia*

**Raudhah Othman** *Faculty of Mechanical and Manufacturing Engineering, Unviersiti Tun Hussein Onn Malaysia, Parti Raja, Malaysia*

**Sani Amril Samsudin** *Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia*

**Satharoorbni Munandi** *Chemical Reaction Engineering Group (CREG), Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia*

**Siti Nor Aishah Ismail** *Chemical Reaction Engineering Group (CREG), Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia*

**Siti Pauliena Mohd Bohari** *Department of Biosciences, Faculty of Science, Universiti Teknologi Malaysia, Johor Bahru, Malaysia*

**Wan Nor Nadyaini Wan Omar** *Chemical Reaction Engineering Group (CREG), Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia*

**Zaki Yamani Zakaria** *Chemical Reaction Engineering Group (CREG),  
Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia,  
Johor Bahru, Malaysia*

**Zahidah Husna Hassan** *Chemical Reaction Engineering Group  
(CREG), Faculty of Chemical and Energy Engineering, Universiti Teknologi  
Malaysia, Johor Bahru, Malaysia*



# Preface

In recent years, the field of biomass conversion has witnessed remarkable growth and innovation, driven by the urgent needs for sustainable alternatives to traditional fossil-based resources. This edited book, *Sustainable Innovations in Biomass Transformation to Chemicals, Fuels, and Materials* stands as an evidence to the collective effort of experts in the field who have contributed their insights and research findings to shape the landscape of renewable resource utilization.

The chapters in this book delve into various facets of biomass conversion, offering a comprehensive exploration of techniques, processes, and applications that bridge the gap between environmental responsibility and technological advancement. Through meticulous research and analysis, the authors of these chapters have illuminated pathways toward more sustainable and environmentally friendly practices.

The authors of these chapters are esteemed experts who have dedicated their careers to unraveling the intricacies of biomass transformation. Their collective efforts have culminated in a book that not only highlights the current state of the art but also points toward the promising future of sustainable resource utilization.

We extend our gratitude to the contributors for their dedication and scholarly insights that have shaped this book. Their commitment to advancing the field of biomass conversion is commendable, and we are honored to present their work within these pages.

*Sustainable Innovations in Biomass Transformation to Chemicals, Fuels, and Materials* aspires to be a valuable resource for researchers, students, and professionals seeking a deeper understanding of biomass conversion technologies and their potential to drive positive environmental change in a circular economy. We hope that this book will inspire further exploration, innovation, and collaboration in this crucial field.

**Nor Aishah Saidina Amin**

**Amnani Shamjuddin**

Universiti Teknologi Malaysia

**2023**