

# Sustainable Catalysis for Biorefineries

## Green Chemistry Series

### *Editor-in-chief:*

James H. Clark, *Department of Chemistry, University of York, UK*

### *Series editors:*

George A. Kraus, *Iowa State University, USA*

Andrzej Stankiewicz, *Delft University of Technology, The Netherlands*

Peter Siedl, *Federal University of Rio de Janeiro, Brazil*

### *Titles in the series:*

- 1: The Future of Glycerol: New Uses of a Versatile Raw Material
- 2: Alternative Solvents for Green Chemistry
- 3: Eco-Friendly Synthesis of Fine Chemicals
- 4: Sustainable Solutions for Modern Economies
- 5: Chemical Reactions and Processes under Flow Conditions
- 6: Radical Reactions in Aqueous Media
- 7: Aqueous Microwave Chemistry
- 8: The Future of Glycerol: 2nd Edition
- 9: Transportation Biofuels: Novel Pathways for the Production of Ethanol, Biogas and Biodiesel
- 10: Alternatives to Conventional Food Processing
- 11: Green Trends in Insect Control
- 12: A Handbook of Applied Biopolymer Technology: Synthesis, Degradation and Applications
- 13: Challenges in Green Analytical Chemistry
- 14: Advanced Oil Crop Biorefineries
- 15: Enantioselective Homogeneous Supported Catalysis
- 16: Natural Polymers Volume 1: Composites
- 17: Natural Polymers Volume 2: Nanocomposites
- 18: Integrated Forest Biorefineries
- 19: Sustainable Preparation of Metal Nanoparticles: Methods and Applications
- 20: Alternative Solvents for Green Chemistry: 2nd Edition
- 21: Natural Product Extraction: Principles and Applications
- 22: Element Recovery and Sustainability
- 23: Green Materials for Sustainable Water Remediation and Treatment
- 24: The Economic Utilisation of Food Co-Products
- 25: Biomass for Sustainable Applications: Pollution Remediation and Energy
- 26: From C-H to C-C Bonds: Cross-Dehydrogenative-Coupling
- 27: Renewable Resources for Biorefineries
- 28: Transition Metal Catalysis in Aerobic Alcohol Oxidation
- 29: Green Materials from Plant Oils
- 30: Polyhydroxyalkanoates (PHAs) Based Blends, Composites and Nanocomposites

- 31: Ball Milling Towards Green Synthesis: Applications, Projects, Challenges
- 32: Porous Carbon Materials from Sustainable Precursors
- 33: Heterogeneous Catalysis for Today's Challenges: Synthesis, Characterization and Applications
- 34: Chemical Biotechnology and Bioengineering
- 35: Microwave-Assisted Polymerization
- 36: Ionic Liquids in the Biorefinery Concept: Challenges and Perspectives
- 37: Starch-based Blends, Composites and Nanocomposites
- 38: Sustainable Catalysis: With Non-endangered Metals, Part 1
- 39: Sustainable Catalysis: With Non-endangered Metals, Part 2
- 40: Sustainable Catalysis: Without Metals or Other Endangered Elements, Part 1
- 41: Sustainable Catalysis: Without Metals or Other Endangered Elements, Part 2
- 42: Green Photo-active Nanomaterials
- 43: Commercializing Biobased Products: Opportunities, Challenges, Benefits, and Risks
- 44: Biomass Sugars for Non-Fuel Applications
- 45: White Biotechnology for Sustainable Chemistry
- 46: Green and Sustainable Medicinal Chemistry: Methods, Tools and Strategies for the 21st Century Pharmaceutical Industry
- 47: Alternative Energy Sources for Green Chemistry
- 48: High Pressure Technologies in Biomass Conversion
- 49: Sustainable Solvents: Perspectives from Research, Business and International Policy
- 50: Fast Pyrolysis of Biomass: Advances in Science and Technology
- 51: Catalyst-free Organic Synthesis
- 52: Hazardous Reagent Substitution: A Pharmaceutical Perspective
- 53: Alternatives to Conventional Food Processing: 2nd Edition
- 54: Sustainable Synthesis of Pharmaceuticals: Using Transition Metal Complexes as Catalysts
- 55: Intensification of Biobased Processes
- 56: Sustainable Catalysis for Biorefineries

*How to obtain future titles on publication:*

A standing order plan is available for this series. A standing order will bring delivery of each new volume immediately on publication.

*For further information please contact:*

Book Sales Department, Royal Society of Chemistry, Thomas Graham House,  
Science Park, Milton Road, Cambridge, CB4 0WF, UK  
Telephone: +44 (0)1223 420066, Fax: +44 (0)1223 420247  
Email: [booksales@rsc.org](mailto:booksales@rsc.org)  
Visit our website at [www.rsc.org/books](http://www.rsc.org/books)



# *Sustainable Catalysis for Biorefineries*

Edited by

**Francesco Frusteri**

*Institute for Advanced Energy Technologies “Nicola Giordano”, Italy*

*Email: francesco.frusteri@itae.cnr.it*

**Donato Aranda**

*Universidade Federal do Rio de Janeiro, Brazil*

*Email: donato@eq.ufrj.br*

and

**Giuseppe Bonura**

*Institute for Advanced Energy Technologies “Nicola Giordano”, Italy*

*Email: giuseppe.bonura@itae.cnr.it*



Green Chemistry Series No. 56

Print ISBN: 978-1-78262-963-4

PDF ISBN: 978-1-78801-356-7

EPUB ISBN: 978-1-78801-478-6

ISSN: 1757-7039

A catalogue record for this book is available from the British Library

© The Royal Society of Chemistry 2018

*All rights reserved*

*Apart from fair dealing for the purposes of research for non-commercial purposes or for private study, criticism or review, as permitted under the Copyright, Designs and Patents Act 1988 and the Copyright and Related Rights Regulations 2003, this publication may not be reproduced, stored or transmitted, in any form or by any means, without the prior permission in writing of The Royal Society of Chemistry or the copyright owner, or in the case of reproduction in accordance with the terms of licences issued by the Copyright Licensing Agency in the UK, or in accordance with the terms of the licences issued by the appropriate Reproduction Rights Organization outside the UK. Enquiries concerning reproduction outside the terms stated here should be sent to The Royal Society of Chemistry at the address printed on this page.*

*Whilst this material has been produced with all due care, The Royal Society of Chemistry cannot be held responsible or liable for its accuracy and completeness, nor for any consequences arising from any errors or the use of the information contained in this publication. The publication of advertisements does not constitute any endorsement by The Royal Society of Chemistry or Authors of any products advertised. The views and opinions advanced by contributors do not necessarily reflect those of The Royal Society of Chemistry which shall not be liable for any resulting loss or damage arising as a result of reliance upon this material.*

The Royal Society of Chemistry is a charity, registered in England and Wales, Number 207890, and a company incorporated in England by Royal Charter (Registered No. RC000524), registered office: Burlington House, Piccadilly, London W1J 0BA, UK, Telephone: +44 (0) 207 4378 6556.

For further information see our web site at [www.rsc.org](http://www.rsc.org)

Printed in the United Kingdom by CPI Group (UK) Ltd, Croydon, CR0 4YY, UK