

Green Synthesis of Nanomaterials

Biological and Environmental Applications

Edited by

Archana Chakravarty

Preeti Singh

Saiqa Ikram

R. N. Yadava

WILEY

Green Synthesis of Nanomaterials

Green Synthesis of Nanomaterials

Biological and Environmental Applications

Edited by

Archana Chakravarty

Jamia Millia Islamia; Central University

New Delhi

India

Preeti Singh

Institute of Chemical Technology

Mumbai

India

Saiqa Ikram

Jamia Millia Islamia; Central University

New Delhi

India

R.N. Yadava

Purnea University Bihar,

Bihar

India

WILEY

Copyright © 2024 by John Wiley & Sons, Inc. All rights reserved.

Published by John Wiley & Sons, Inc., Hoboken, New Jersey.

Published simultaneously in Canada.

No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning, or otherwise, except as permitted under Section 107 or 108 of the 1976 United States Copyright Act, without either the prior written permission of the Publisher, or authorization through payment of the appropriate per-copy fee to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923, (978) 750-8400, fax (978) 750-4470, or on the web at www.copyright.com. Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, (201) 748-6011, fax (201) 748-6008, or online at <http://www.wiley.com/go/permission>.

Trademarks: Wiley and the Wiley logo are trademarks or registered trademarks of John Wiley & Sons, Inc. and/or its affiliates in the United States and other countries and may not be used without written permission. All other trademarks are the property of their respective owners. John Wiley & Sons, Inc. is not associated with any product or vendor mentioned in this book.

Limit of Liability/Disclaimer of Warranty: While the publisher and author have used their best efforts in preparing this book, they make no representations or warranties with respect to the accuracy or completeness of the contents of this book and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose. No warranty may be created or extended by sales representatives or written sales materials. The advice and strategies contained herein may not be suitable for your situation. You should consult with a professional where appropriate. 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. 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. For general information on our other products and services or for technical support, please contact our Customer Care Department within the United States at (800) 762-2974, outside the United States at (317) 572-3993 or fax (317) 572-4002.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic formats. For more information about Wiley products, visit our web site at www.wiley.com.

Library of Congress Cataloging-in-Publication Data applied for:

ISBN: HB: 9781119900900, ePDF: 9781119900917, epub: 9781119900924

Cover Design: Wiley

Cover Image(s): © Konstantinos Zouganelis/Getty Images

Set in 9.5/12.5pt STIXTwoText by Straive, Pondicherry, India

Contents

List of Contributors xv

Preface xxi

- 1 Introduction to Advanced and Sustainable Green Nanomaterial** 1
Aayushi Chanderiya, Atish Roy, and Ratnesh Das
- 1.1 Introduction 1
- 1.2 Synthesis Methods of Nanomaterials 4
- 1.3 Green Synthesis 5
- 1.4 Biosynthesis of Nanoparticles from Plants 6
- 1.5 Characterization of Nanomaterials 7
 - 1.5.1 X-ray Diffraction (XRD) 7
 - 1.5.2 Scanning Electron Microscope (SEM) 7
 - 1.5.3 Energy Dispersive X-ray (EDX) 7
 - 1.5.4 Thermogravimetric Analysis (TGA) 8
 - 1.5.5 UV-Visible Spectroscopy (UV-Vis) 8
 - 1.5.6 Asymmetric Flow Field Fractionation (AF4) 8
 - 1.5.7 Electrospray Differential Mobility Analysis (ESDMA) 8
- 1.6 Environmental and Health Concerns 9
- 1.7 Application 9
 - 1.7.1 Use as Sensor 9
 - 1.7.2 Use as Medicine 12
 - 1.7.3 Used for the Removal of Toxicants from Water 12
 - 1.7.4 Soil Redemption Use for the Removal of Toxicants from the Soil 13
 - 1.7.5 In Agriculture and Food Industries 13
 - 1.7.6 Use as Photocatalyst 14
- 1.8 Future Scope 15

1.9	Ongoing Challenges	16
1.10	Conclusion	16
	Abbreviations	17
	References	17
2	Medicinal Plant-Mediated Nanomaterials	22
	<i>Abu Taha, Nowsheenah Farooq, and Athar Adil Hashmi</i>	
2.1	Introduction	23
2.2	Synthesis of Gold Nanoparticles	24
2.3	Synthesis of Silver Nanoparticles	28
2.4	Synthesis of Zinc Oxide Nanoparticles	31
2.5	Synthesis of Titanium Oxide Nanoparticles	34
2.6	Synthesis of Iron Oxide Nanoparticles	35
2.7	Conclusion and Future Perspective	37
	References	38
3	Microorganism-Based Synthesis of Nanomaterials and Their Applications	46
	<i>Khairatun Najwa Mohd Amin, Rohana Abu, Sharifah Fathiyah Sy Mohamad, and Afkar Rabbani Hidayatullah Hipeni</i>	
3.1	Introduction	47
3.2	Microorganism	49
3.2.1	Bacteria	49
3.2.2	Yeast	49
3.2.3	Fungi	49
3.2.4	Virus	50
3.3	Development of Microorganism-Based Synthesis of Nanomaterial	50
3.3.1	Organic Nanomaterial	50
3.3.1.1	Bacterial Nanocellulose (BNC)	50
3.3.2	Inorganic Nanomaterial	51
3.3.2.1	Gold Nanomaterials	52
3.3.2.2	Silver Nanomaterials	52
3.3.3	Other Nanomaterials	52
3.4	Mechanism of Microorganism-Based Synthesis of Nanomaterial	55
3.4.1	Organic Nanomaterial	55
3.4.1.1	Bacterial Nanocellulose (BNC)	55
3.4.2	Inorganic Nanomaterial	56
3.4.2.1	Gold Nanomaterials	56
3.4.2.2	Silver Nanomaterials	57
3.4.3	Other Nanomaterials	59

3.5	Application of Microorganism-Based Synthesized Nanomaterial	60
3.6	Conclusion and Perspective	61
	Abbreviations	61
	References	61
4	Biopolymer-Based Nanomaterials and Their Applications	71
	<i>Baranya Murugan, Is Fatimah, MA Motalib Hossain, and Suresh Sagadevan</i>	
4.1	Introduction	72
4.2	Classification of Biopolymers	73
4.2.1	Sugar-Based Biopolymer	73
4.2.2	Starch-Based Biopolymer	74
4.2.3	Cellulose-Based Biopolymers	74
4.2.4	Lignin-Based Biopolymers	74
4.2.5	Biopolymers Based on Synthetic Materials	74
4.3	Synthesis Methods of Biopolymers	75
4.4	Characterization Methods of Biopolymers	75
4.5	Nanotechnology-Based Applications of Biopolymers	77
4.5.1	Drug Delivery Systems	78
4.5.2	Medical Implants	79
4.5.3	Antimicrobial Activity of Biopolymers	80
4.5.4	Wound Healing	80
4.5.5	Tissue Engineering Applications	81
4.5.6	Food Packaging Material	81
4.6	Conclusions	82
	Acknowledgments	83
	Conflict of Interest	83
	References	83
5	Photoinduced Synthesis of Nanoparticles	89
	<i>Nowsheenah Farooq, Abu Taha, and Athar Adil Hashmi</i>	
5.1	Introduction	90
5.1.1	Role of Nanomaterials	90
5.2	Methods of Synthesis	92
5.2.1	Physical Synthesis of Nanomaterials	92
5.2.2	Chemical Synthesis of Nanomaterials	92
5.3	Photochemical Synthesis of Nanomaterials	94
5.3.1	Synthesis of Gold Nanoparticles Using Ultraviolet Light	96
5.3.1.1	Influence of pH	96
5.3.1.2	Influence of Precursor Concentration	97
5.3.2	Synthesis of Silver Nanoparticles Using Ultraviolet Light	98

- 5.3.2.1 Influence of pH 98
- 5.3.2.2 Influence of Reducing Agents 98
- 5.3.3 Synthesis of Gold Nanoparticles Under Visible Light 99
- 5.3.4 Synthesis of Silver Nanoparticles Under Visible Light 100
- 5.4 Photochemical Synthesis of UO_2 Nanoparticles in Aqueous Solutions 100
- 5.5 Photochemical Synthesis of ZnO Nanoparticles 101
- 5.6 Conclusion 102
- Abbreviations 103
- References 103

6 Green Nanomaterials in Textile Industry 114

Indu Kumari, Sarabjeet Kaur, and Ratnesh Das

- 6.1 Introduction 115
- 6.2 Nanomaterials Consistent with Textiles 116
- 6.3 Techniques Related to Textile Functionalization 117
 - 6.3.1 Pad Dry Cure Method 117
 - 6.3.2 *In Situ* Preparation 118
 - 6.3.3 Green Nanotechnology 118
- 6.4 Utilization of Nanotechnology in Textile Industry 120
 - 6.4.1 Nanofinishing 120
 - 6.4.2 Nanofibers 120
 - 6.4.3 Nanocoating 120
 - 6.4.4 Nanocomposite 121
- 6.5 Nanomaterials with Different Functional Textiles 121
 - 6.5.1 UV-Protective Textiles 122
 - 6.5.2 Flame-Retardant Textile 123
 - 6.5.3 Repellent Textiles 123
 - 6.5.4 Antibacterial and Antimicrobial Textiles 124
 - 6.5.5 Wrinkle-Free Textiles 124
 - 6.5.6 Antiodor Textiles 125
- 6.6 Conclusion 125
- Conflict of Interest 126
- References 126

7 Drug-delivery, Antimicrobial, Anticancerous Applications of Green Synthesized Nanomaterials 131

Sivasubramanian Murugappan, Monika Pebam, Sri Amruthaa Sankaranarayanan, and Aravind Kumar Rengan

- 7.1 Introduction 132
- 7.2 Gold Nanoparticles 133

7.2.1	Synthesis of AuNPs	133
7.2.2	AuNPs in Drug Delivery	134
7.2.3	Antimicrobial Activity of AuNPs	135
7.2.4	Anticancer Activity of AuNPs	135
7.3	Silver Nanoparticles	137
7.3.1	Synthesis of AgNPs	137
7.3.2	AgNPs in Drug Delivery	138
7.3.3	Antimicrobial Activity of AgNPs	139
7.3.4	Anticancer Activity of AgNPs	140
7.4	Zinc Oxide Nanoparticles	141
7.4.1	Synthesis of ZnO NPs	141
7.4.2	Role of ZnO NPs in Drug Delivery	142
7.4.3	Antimicrobial Activity of ZnO NPs	142
7.4.4	Anticancer Activity of ZnO NPs	145
7.5	Titanium Dioxide Nanoparticles	147
7.5.1	Synthesis of Titanium Dioxide NPs (TiO ₂ NPs)	147
7.5.2	TiO ₂ NPs in Drug Delivery	147
7.5.3	Antibacterial Activities of TiO ₂ NPs	148
7.5.4	Anticancer Activities of TiO ₂ NPs	149
7.6	Iron Oxide Nanoparticles	150
7.6.1	Synthesis of IONPs	150
7.6.2	IONPs in Drug Delivery	151
7.6.3	Antibacterial Activity of IONPs	151
7.6.4	Anticancer Activity of IONPs	152
7.7	Carbon Based Nanomaterials	153
7.7.1	Synthesis of Carbon-Based Nanomaterials	153
7.7.2	Carbon Based Nanomaterials in Drug Delivery	154
7.7.3	Antimicrobial Activity of Carbon-Based Nanomaterials	155
7.7.4	Anticancer Activity of Carbon-Based Nanomaterials	156
7.8	Conclusion and Future Directions	156
	Acknowledgment	157
	Conflicts of Interest	157
	References	157
8	How Eco-friendly Nanomaterials are Effective for the Sustainability of the Environment	169
	<i>Manoj Kumar, Preeti Sharma, Archana Chakravarty, Sikandar Paswan, and Deepak Kumar Bhartiya</i>	
8.1	Introduction	170
8.2	Eco-friendly Nanomaterials	172
8.3	Green Nanomaterial for Removal of Water Contamination	175

- 8.4 Green Nanomaterial for Removal of Soil Pollution 178
- 8.5 Conclusion 179
- References 180

9 Magnetotactic Bacteria-Synthesized Nanoparticles and Their Applications 187

Juhi Gupta and Athar Adil Hashmi

- 9.1 Introduction 188
 - 9.1.1 Magnetotactic Bacteria (MTB) 188
 - 9.1.2 Types of MTB 189
- 9.2 Characteristics of Magnetosomes (MNPs)—Biogenic NPs and Their Physico-Chemical Properties 190
- 9.3 Synthesis of Magnetosomes 193
- 9.4 MNPs Relative to Chemically Synthesized NPs 194
- 9.5 Applications of Magnetosomes 197
 - 9.5.1 Magnetosomes in Functionalization and Immobilization of Bio-active Molecules 197
 - 9.5.2 Magnetosomes in DNA, Xenobiotics and Antigen Detection Assays 198
 - 9.5.3 Treatment of Magnetic Hyperthermia 199
 - 9.5.4 Food Safety 199
 - 9.5.5 Cell Separation 199
 - 9.5.6 Drug Delivery 200
- 9.6 Conclusion and Future Perspective 200
- References 201

10 Biofabrication of Nanoparticles in Wound-Healing Materials 208

Nishat Khan, Isha Arora, Amrisha Chandra, and Seema Garg

- 10.1 Introduction 209
- 10.2 Nanoparticles 215
 - 10.2.1 Silver Nanoparticles 215
 - 10.2.2 Gold Nanoparticles 216
- 10.3 Nanocomposites or Composite Nanoparticles 216
- 10.4 Coatings and Scaffolds 218
- 10.5 Green Synthesis of Silver Nanoparticles 220
 - 10.5.1 Synthesis of Silver Nanoparticles by Aqueous Extract of *Arnebia nobilis* Roots 222
 - 10.5.2 Honey-Based Nanoparticles in Wound-Healing Process 224
- 10.6 Conclusion 225
- Abbreviations 225
- References 226

11	Cellulosic Nanomaterials for Remediation of Greenhouse Effect	228
	<i>Athanasia Amanda Septevani, Melati Septiyanti, Annisa Rifathin, David Natanael Vicarneltor, Yulianti Sampora, Benni F. Ramadhoni, and Sudiyarmanto</i>	
11.1	Introduction	229
11.1.1	Fundamentals of the Greenhouse Effect	229
11.1.2	Cellulosic Contribution to the Remediation of Greenhouse Effect	229
11.2	Cellulosic Nanomaterials in Automotive Application	230
11.2.1	Nanocellulose-Enabled Lightweight Vehicles	231
11.2.2	Processing and Performance of Nanocellulose in Automotive Parts	232
11.3	Cellulosic Nanomaterials in the Application of Thermal Insulation	233
11.3.1	Nanocellulose Reinforced Polymeric Insulation Toward Zero Energy Usage	234
11.3.2	Processing and Performance of Nanocellulose in Insulation Material	235
11.4	Cellulosic Nanomaterial for Gas Capture and Separation	236
11.4.1	Nanocellulosic Membrane for Capturing/Separating Greenhouse Gases	237
11.4.2	Processing and Performance of Nanocellulose Membrane for Gas Capture and Separation	238
11.5	Conclusion and Future Prospective	239
	Abbreviation	240
	References	241
12	Ecofriendly Nanomaterials for Wastewater Treatment	248
	<i>Neeru Dabas, Shivani Chaudhary, Ritu Rani Chaudhary, and Gautam Jaiswar</i>	
12.1	Introduction	249
12.2	Application of Ecofriendly Nanomaterials	249
12.3	Inorganic Nanoparticles	251
12.4	Synthesis of Green Nanomaterials	252
12.5	Nanocellulose Nanomaterials for Water Treatment	253
12.6	Graphene-CNT Hybrid/Graphene Hybrids (GO and Biopolymer)	254
12.7	Green Nanocomposite	256
12.7.1	Guar Gum-Based Nanocomposites	257
12.8	Ecofriendly Nanomaterials from Agricultural Wastes	259
12.8.1	Ecofriendly Nanomaterials for Clean Water	260

- 12.8.2 Clay-Based Material are Also Used for Wastewater Treatment 263
- 12.9 Conclusion 264
 - Financial Support 264
 - Abbreviations 264
 - References 265

- 13 Bio-nanomaterials from Agricultural Waste and Its Applications 270**
Shaily, Adnan Shahzaib, Fahmina Zafar, and Nahid Nishat
- 13.1 Introduction 271
- 13.2 Lignin 272
 - 13.2.1 Lignin Nanocomposites (NCs) 274
 - 13.2.2 Lignin-Based Catalysts and Photocatalyst 274
 - 13.2.3 Lignin-Based NC Coatings 276
- 13.3 Cashew Nut Shell Liquid (CNSL) 276
 - 13.3.1 CNSL NC-Based Surfactants 278
 - 13.3.2 CNSL-Based NC Films/Coatings 279
 - 13.3.3 CNSL-Based PU Coatings 279
- 13.4 Vegetable/Fruit Waste 284
 - 13.4.1 Vegetable/Fruit Waste-Induced Nanomaterials 285
 - 13.4.2 Medicinal Activities of Vegetable/Fruit Waste 286
- 13.5 Conclusion 286
 - Acknowledgments 287
 - Abbreviation 287
 - References 287

- 14 Peptide-Assisted Synthesis of Nanoparticles and Their Applications 292**
Vikas Kumar
- 14.1 Introduction 292
- 14.2 Synthesis of Metal Nanoparticles by Using Peptides as Template 295
 - 14.2.1 In the Presence of Reducing Agents 295
 - 14.2.2 In the Absence of Reducing Agent 295
- 14.3 Characterization of Peptide-MNP Hybrids 295
 - 14.3.1 UV-Visible Spectroscopy/Surface Plasmon Resonance (SPR) Spectroscopy 296
 - 14.3.2 Fluorescence Spectroscopy 297
 - 14.3.3 Circular Dichroism 297
 - 14.3.4 Ultrafiltration and Centrifugation 297

- 14.3.5 Zeta Potential Study 298
- 14.3.6 Dynamic Light Scattering (DLS) 298
- 14.3.7 Transmission Electron Microscopy (TEM) 298
- 14.3.8 X-ray Diffraction Analysis 299
- 14.3.9 Matrix Laboratory (MATLAB) Analysis 299
- 14.3.10 ImageJ Analysis 300
- 14.3.11 Atomic Force Microscopy (AFM) 300
- 14.4 Biological and Environmental Applications of Peptide Nanoparticles 301
 - 14.4.1 Peptide-Assisted Synthesis of Silver Nanoparticles and Their Applications 302
 - 14.4.2 Peptide-Assisted Synthesis of Gold Nanoparticles and Their Applications 305
 - 14.4.3 Synthesis of Core-Shell Bimetallic Nanoparticles and Their Catalytic Application of Metal Nanoparticles 308
- 14.5 Conclusion 308
 - Abbreviations 309
 - References 310

15 Pharmacotherapy Approach of Peptide-Assisted Nanoparticle 317

Shivani A. Kumar, Rimon Ranjit Das, and Surbhi Malik

- 15.1 Introduction 317
- 15.2 The Peptide-NP Conjugation 319
- 15.3 Targeted Drug Delivery 321
- 15.4 Pathogenic Protein Interaction Inhibition 323
- 15.5 Molecular Imaging 326
- 15.6 Liquid Biopsy 329
- 15.7 Summary and Outlook 331
 - Abbreviations 332
 - References 333

16 Unleashing the Potential of Green-Synthesized Nanoparticles for Effective Biomedical Application 343

G.K. Prashanth, Manoj Gadewar, M. Mutthuraju, Srilatha Rao, A.S. Sowmyashree, K. Shwetha, Mithun Kumar Ghosh, B.R. Malini, and Vinita Chaturvedi

- 16.1 Introduction 344
- 16.2 Synthesis and Characterization of NPs 345
- 16.3 GNPs as Anti-Carcinogens 346
- 16.4 Green NPs as Anti-Microbials 348

16.5	Applications of Green NPs in Another Drug Delivery	354
16.6	Conclusion	354
	Acknowledgments	356
	References	356

Index	369
--------------	-----

List of Contributors

Rohana Abu

Faculty of Chemical and Process
Engineering Technology
Universiti Malaysia Pahang Al-Sultan
Abdullah. Persiaran Tun Kalil
Yaakob, Gambang Kuantan, Pahang
Malaysia

Khairatun Najwa Mohd Amin

Faculty of Chemical and Process
Engineering Technology
Universiti Malaysia Pahang Al-Sultan
Abdullah. Persiaran Tun Kalil
Yaakob, Gambang Kuantan, Pahang
Malaysia

Isha Arora

Department of Chemistry
Amity Institute of Applied
Sciences, Amity University
Noida, UP
India

Deepak Kumar Bhartiya

Department of Zoology
Government Degree College
Dhadha Bujurg-Hata
Kushinagar, UP
India

Archana Chakravarty

Department of Chemistry
Jamia Millia Islamia
New Delhi, Delhi
India

Aayushi Chanderiya

Department of Chemistry
Dr. Harisingh Gour University
Sagar, MP
India

Amrish Chandra

Amity Institute of Pharmacy
Amity University
Noida, UP
India

Vinita Chaturvedi

Biochemistry Division
Central Drug Research Institute
CSIR Lucknow, UP
India

Ritu Rani Chaudhary

Department of Chemistry
B.S.A. College
Mathura, UP
India

Shivani Chaudhary

Department of Chemistry
Dr. Bhimrao Ambedkar University
Agra, UP
India

Neeru Dabas

Department of Chemistry
Amity School of Applied Science
Amity University
Gurugram, HR
India

Ratnesh Das

Department of Chemistry
Dr. Harisingh Gour Central
University
Sagar, MP
India

Rimon Ranjit Das

Department of Physics
Amity Institute of Applied
Sciences, Amity University
Noida, UP
India

Newsheenah Farooq

Bioinorganic Lab
Department of Chemistry
Jamia Millia Islamia
New Delhi, DL
India

Is Fatimah

Department of Chemistry
Faculty of Mathematics and
Natural Sciences
Universitas Islam Indonesia
Yogyakarta
Indonesia

Manoj Gadewar

Department of Pharmacology
School of Medical and Allied
Sciences, KR Mangalam University
Gurgaon, HR
India

Seema Garg

Department of Chemistry
Amity Institute of Applied
Sciences, Amity University
Noida, UP
India

Mithun Kumar Ghosh

Department of Chemistry
Government College Hatta
Damoh
India

Juhi Gupta

Bioinorganic Research Lab
Department of Chemistry
Jamia Millia Islamia
New Delhi, DL
India

Athar Adil Hashmi

Bioinorganic Lab
Department of Chemistry
Jamia Millia Islamia
New Delhi, DL
India

Afkar Rabbani Hidayatullah Hipeni

Faculty of Chemical and Process
Engineering Technology
Universiti Malaysia Pahang Al-Sultan
Abdullah. Persiaran Tun Kalil
Yaakob, Gambang Kuantan, Pahang
Malaysia

MA Motalib Hossain

Institute of Sustainable Energy
Universiti Tenaga Nasional
Kajang, Selangor
Malaysia

Gautam Jaiswar

Department of Chemistry
Dr. Bhimrao Ambedkar
University
Agra, UP
India

Sarabjeet Kaur

Surface Chemistry and Catalysis:
Characterisation and Application
Team (COK-KAT), Leuven
(Arenberg)
Leuven
Belgium

Nishat Khan

Department of Chemistry
Amity Institute of Applied
Sciences, Amity University
Noida, UP
India

Manoj Kumar

Department of Chemistry
Government Degree College
Dhadha Bujurg-Hata
Kushinagar, UP
India

Vikas Kumar

Department of Chemistry
Government College Khimlasa
Sagar, MP
India

Shivani A. Kumar

Department of Physics
Amity Institute of Applied
Sciences, Amity University
Noida, UP
India

Indu Kumari

CT Group of Institutions
Jalandhar, PB
India

Surbhi Malik

Department of Physics
Amity Institute of Applied
Sciences, Amity University
Noida, UP
India

B.R. Malini

Department of Chemistry
Akshara First Grade College
Bengaluru, KA
India

Sharifah Fathiyah Sy Mohamad

Faculty of Chemical and Process
Engineering Technology
Universiti Malaysia Pahang Al-Sultan
Abdullah. Persiaran Tun Kalil
Yaakob, Gambang Kuantan, Pahang
Malaysia

Baranya Murugan

Nanotechnology & Catalysis
Research Centre
University of Malaya
Kuala Lumpur
Malaysia

Sivasubramanian Murugappan

Department of Biomedical
Engineering
Indian Institute of Technology
Hyderabad
Sangareddy, TS
India

M. Mutthuraju

Department of Chemistry
Sai Vidya Institute of Technology
Affiliated to Visvesvaraya
Technological University
Bengaluru, KA
India

Nahid Nishat

Inorganic Materials Research Lab
Department of Chemistry
Jamia Millia Islamia
New Delhi, DL
India

Sikandar Paswan

Department of Chemistry
Baba Raghav Das PG College
Deoria, UP
India

Monika Pebam

Department of Biomedical
Engineering
Indian Institute of Technology
Hyderabad
Sangareddy, TS
India

G.K. Prashanth

Research and Development Centre
Department of Chemistry
Sir M. Visvesvaraya Institute
of Technology, Affiliated to
Visvesvaraya Technological
University
Bengaluru, KA
India

Benni F. Ramadhoni

National Research and
Innovation Agency
Tangerang Selatan
Indonesia

Srilatha Rao

Department of Chemistry
Nitte Meenakshi Institute of
Technology
Affiliated to Visvesvaraya
Technological University
Bengaluru, KA
India

Aravind Kumar Rengan

Department of Biomedical
Engineering
Indian Institute of Technology
Hyderabad
Sangareddy, TS
India

Annisa Rifathin

National Research and
Innovation Agency
Tangerang Selatan
Indonesia

Atish Roy

Department of Chemistry
Dr. Harisingh Gour University
Sagar, MP
India

Suresh Sagadevan

Nanotechnology & Catalysis
Research Centre
University of Malaya
Kuala Lumpur
Malaysia

Department of Chemistry
Faculty of Mathematics and
Natural Sciences
Universitas Islam Indonesia
Yogyakarta
Indonesia

Yulianti Sampora

National Research and
Innovation Agency
Tangerang Selatan
Indonesia

Sri Amrutha Sankaranarayanan

Department of Biomedical
Engineering
Indian Institute of Technology
Hyderabad
Sangareddy, TS
India

Athanasia Amanda Septevani

National Research and
Innovation Agency
Tangerang Selatan
Indonesia

Melati Septiyanti

National Research and
Innovation Agency
Tangerang Selatan
Indonesia

Shaily

Inorganic Materials Research Lab
Department of Chemistry
Jamia Millia Islamia
New Delhi, DL
India

Adnan Shahzaib

Inorganic Materials Research Lab
Department of Chemistry
Jamia Millia Islamia
New Delhi, DL
India

Preeti Sharma

Department of Natural Sciences
University of Maryland
Eastern Shore
Princess Anne, MD
USA

K. Shwetha

Department of Chemistry
Nitte Meenakshi Institute of
Technology
Bengaluru, KA
India

A.S. Sowmyashree

Department of Chemistry
Nitte Meenakshi Institute of
Technology
Bengaluru, KA
India

Sudiyarmanto

National Research and
Innovation Agency
Tangerang Selatan
Indonesia

Abu Taha

Bioinorganic Lab
Department of Chemistry
Jamia Millia Islamia
New Delhi, DL
India
India

David Natanael Vicarneltor

National Research and
Innovation Agency
Tangerang Selatan
Indonesia

Fahmina Zafar

Inorganic Materials Research Lab
Department of Chemistry
Jamia Millia Islamia
New Delhi, DL
India

Preface

Nanotechnology and materials science have made remarkable advances in recent years, revolutionizing several industries and creating new opportunities for research and development. Nanomaterials, with their distinct physical and chemical characteristics at the nanoscale, have drawn a lot of interest and are being investigated for a wide range of applications, from electronics and energy to medicine and environmental remediation.

However, despite these promising prospects, there is rising worry regarding the sustainability and environmental impact of the conventional synthesis techniques used to create nanomaterials. Conventional methods frequently employ hazardous chemicals, consume a lot of energy, and produce a lot of waste, which raises severe concerns about their long-term effects and ecological imprint.

To overcome these issues and open the door to the manufacture of sustainable nanomaterials, the idea of “green synthesis” has evolved in this context. Utilizing both ecologically friendly natural resources including plants, microorganisms, and other natural resources, as well as green synthetic techniques, can be used to create nanomaterials.

This book, *Green Synthesis of Nanomaterials: Biological and Environmental Applications*, examines the developing area of “green synthesis of nanomaterials” and its potential biological and environmental pollution remediation applications. It explores the numerous biological sources and fabrication techniques used for the environmentally friendly production of nanomaterials, highlighting their special benefits, constraints, and possible uses.

In addition to highlighting the biological and environmental uses of the synthesized nanomaterials, the goal of this book is to provide a thorough and informative overview of the state-of-the-art methods and developments in green synthesis. The chapters include a wide range of subjects, such as biosynthesis by employing plants and bacteria, as well as the use of natural substances like cellulose and peptide for the green synthesis and

biofabrication of nanomaterials and their applications in biomedical as well as environmental pollution remediation.

Readers will obtain a thorough grasp of the concepts driving green synthesis, the characterization methods used for nanomaterial analysis, and the wide range of applications in the biological and environmental domains throughout every chapter of this book. The potential applications of green nanomaterials are numerous and exciting, ranging from pollutant removal to antibacterial agents and targeted medication delivery systems.

This book is a useful resource for students, scientists, engineers, and business executives alike since the contributing authors leading academics and authorities in their respective fields have contributed their wealth of knowledge and expertise. Their combined efforts have produced a thorough compilation that not only illuminates the possibilities of green synthesis but also adds to the continuing discussion about sustainable nanotechnology.

We hope that this book will act as a catalyst for additional study, encouraging scientists to delve more deeply into the field of green synthesis and promoting the creation of brand-new, environmentally friendly nanomaterials. We may work towards a better future where scientific progress and environmental responsibility go hand in hand by harnessing the power of nature and implementing sustainable practices.

We would like to extend our sincere gratitude to everyone who helped with the writing, reviewing, and publishing of this book. We would also like to express our gratitude to the readers for their attention and participation. We can create the conditions for a sustainable and ecologically conscientious future by working together and exchanging knowledge.

1

Introduction to Advanced and Sustainable Green Nanomaterial

Aayushi Chanderiya, Atish Roy, and Ratnesh Das

Department of Chemistry, Dr. Harisingh Gour University, Sagar, MP, India

Abstract

A magical period of scientific observation and science-based regeneration is required to advance human civilization. Technological developments are brimming with deep scientific insight and depth. Today's sustainability is in the midst of a significant crisis. Energy and environmental sustainability are critical for the advancement of human civilization. Sustainable construction is the bedrock of scientific destiny and profound scientific progress. In this chapter, the authors primarily concentrated on the success of green sustainability, synthesis, nanoscience's vast implementation range, and the novel field of specialized and sustainable nanomaterials. The other pillars of this scientific endeavor are expansion efforts. Green and environmental sustainability are today's human forerunners.

Keywords *sustainability; environmental sustainability; scientific progress; nanoscience; green sustainability; green engineering*

1.1 Introduction

Nanotechnology is characterized as the science of the small. It is the manipulation of materials on a microscopic scale. Atoms and molecules behave differently when they are little. These particles have distinct characteristics. It has a wide range of extraordinary and intriguing applications, and research in nanotechnology and nanoscience has exploded across

various product areas. It allows for the creation and progress of materials, including medicinal usage, environmental redemption, and so on. Conventional methods may have reached their limits. However, nanotechnology is advancing in a variety of ways. As a result, nanotechnology should not be considered a singular approach that only affects specific research fields; instead, it should be viewed as an exploration of all science disciplines [1a]. Modern green methods are regarded as one of the best aspects to prevent and enhance the environment to achieve sustainable improvement. This concept has piqued the interest of scientists in adopting its principles about indicators of environmental efficiency by demonstrating the real benefit in the stages of planning, design, utilization, and sustainability in multiple vital sectors of the human being [1b, 1c, 2]. Because of their distinct size-dependent qualities, these materials are exceptional and necessary in a wide range of human activities [3]. Nanotechnology covers a wide range of subjects, from adaptations of classical equipment physics to revolutionary tactics centered on molecular self-assembly, from developing products with nanoscale size to determining if we can directly influence things on the atomic scale/level [4] (Figure 1.1).

Several science policy publications show significant potential and value in offering green nano methods that produce nanomaterials and products without pollutants that impair the environment or human health at the management, design, production, and methodology phases. As a result, nanotechnology may help to alleviate issues about safe, sustainable development, such as environmental, human health, and safety issues, as well as assist in a sustainable environment in terms of energy, water, food supply, raw substances, environmental issues, and so on [5].

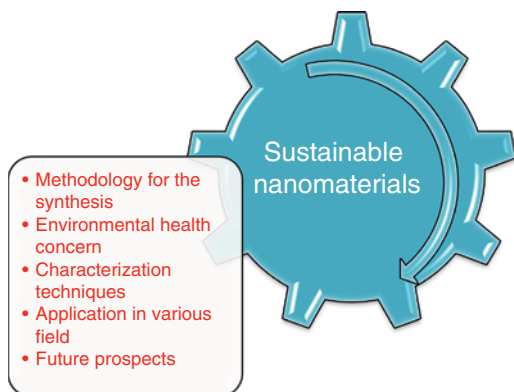


Figure 1.1 Sustainable nanomaterials.

- Advanced nanomaterials are the intelligent materials of today's human society. Advanced nanomaterials may be characterized in a variety of ways. The most extended term refers to any materials that reflect advancements above conventional materials that have been utilized for hundreds, if not thousands, of years. Consider materials early in their product and technology life cycles for a better understanding description of innovative materials.
- What is a sustainable nanomaterial?
Sustainability is concerned with the needs of the current and coming years' decades. Nanomaterials are at the cutting edge of nanotechnology, which is continually evolving. Because of their distinctive size-dependent qualities, these materials are exceptional and necessary in many human activities.
- Sustainable and green nanomaterial
Nanoparticles are particles with diameters ranging from 1 to 100 nm [6]. Depending on the shape, nanoparticles can be 0D, 1D, 2D, or 3D [7]. The relevance of these nanoparticles became apparent when researchers discovered that particle size might alter the physiochemical characteristics of substances, such as optical qualities. The nanoparticles are divided into many categories based on their morphology, size, and form (Figures 1.2–1.4).

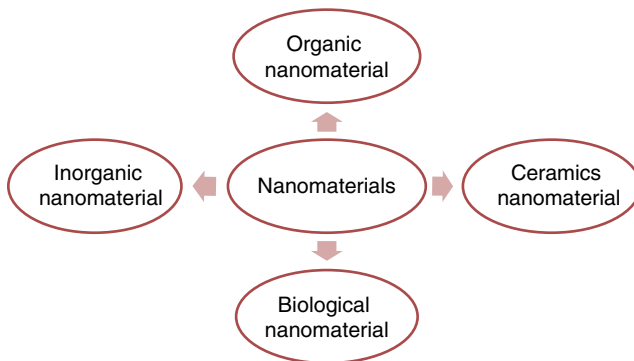


Figure 1.2 Types of nanomaterials.

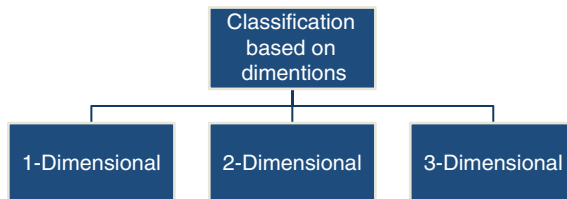


Figure 1.3 Classification based on dimensions of nanomaterials.

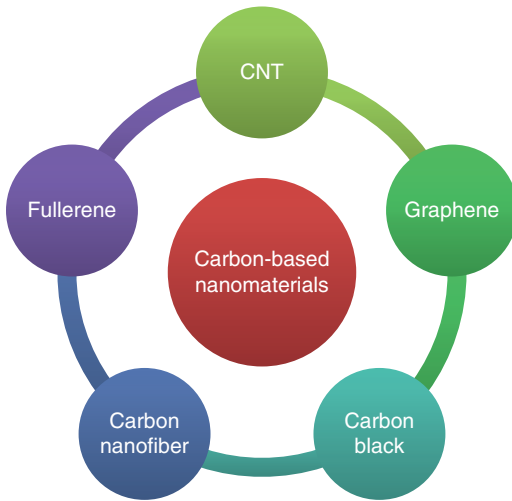


Figure 1.4 Carbon-based nanomaterials.

1.2 Synthesis Methods of Nanomaterials

Metal nanoparticles may be created in a variety of methods. There are two types of conversion methodologies: top-down and bottom-up. Several nanoparticle synthesis processes have been developed, and they are suitable for synthesizing nanoparticles of various sizes and shapes. The top-down technique is destructive, breaking down large molecules into tiny parts before changing them into the desired nanoparticles. Decomposition methods such as chemical vapor deposition (CVD), grinding, and physical vapor deposition (PVD) are used in this procedure. Milling is used to remove nanoparticles from coconut shells, with the size of the crystallites decreasing with time. This method produced iron oxide, carbon, dichalcogenides, and cobalt (III) oxide nanoparticles.

Bottom-up strategy method includes the gradual synthesis of nanoparticles from basic materials. It is least harmful to the environment, more practicable, and less expensive. Typically, the materials used in reduction and sedimentation techniques include green synthesis, biochemical, spin coating, sol-gel, and so on. This method has been used to create titanium dioxide, gold, and bismuth nanoparticles (Figure 1.5).

Nanoparticle synthesis might potentially utilize chemical or biological mechanisms [8]. Some chemical synthesis strategies for nanoparticles include the sol-gel method, wet chemical synthesis, hydrothermal method,

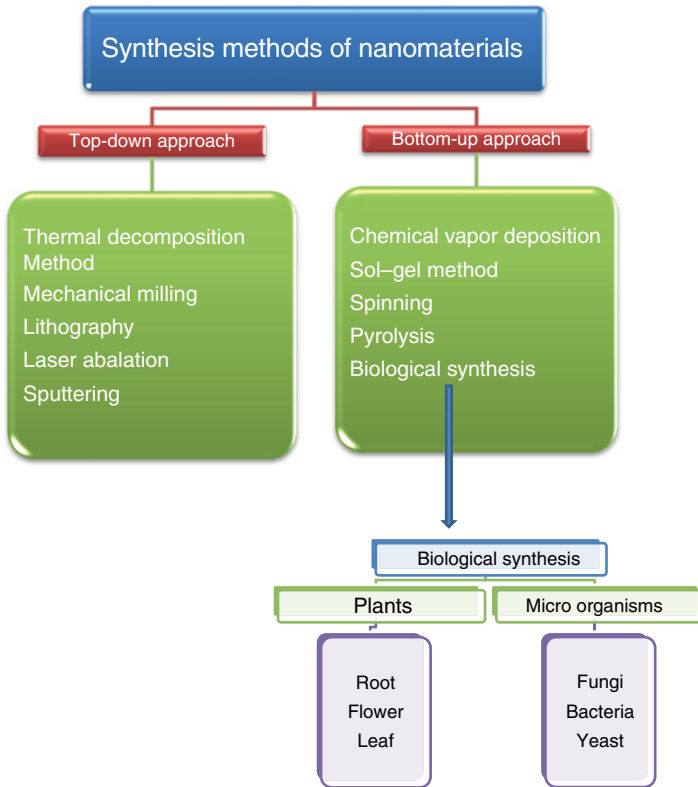


Figure 1.5 Synthesis methods of nanomaterials.

thermal decomposition, microwave method, and so on [9]. In contrast, biological processes contain enzymes, bacteria, plant extracts, and fungi.

1.3 Green Synthesis

Green chemistry and its ideas and environmental efficiency metrics are frequently viewed as fundamental to creating long-term profitability. Green chemistry principles include prevention, atom economy, less hazardous chemical synthesis, safer compound development, energy-efficient design, employing renewable fuel sources, catalysis, and constructing for decay. Green nanomaterial synthesis is an environmentally friendly method of nanomaterial synthesis that employs nontoxic, biodegradable ingredients. This method may be used to mass-produce nanomaterials on a

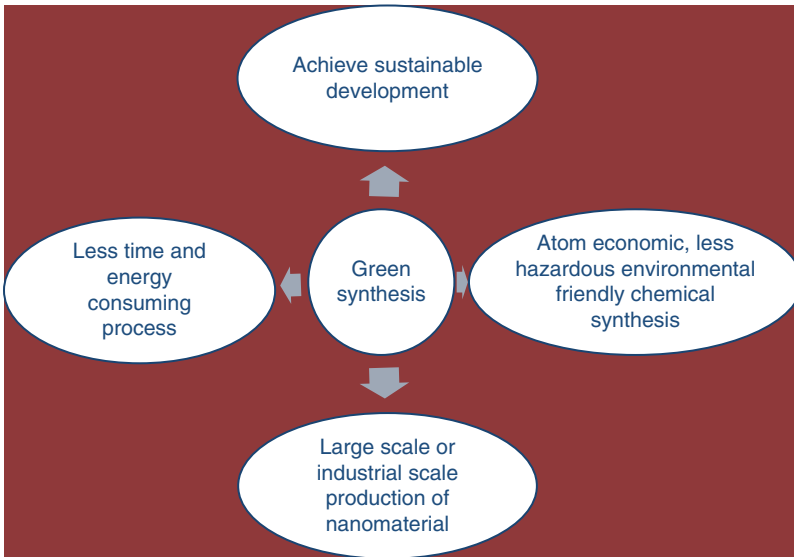


Figure 1.6 Advantages of green synthesis.

considerable scale. In green synthesis, the external experimental conditions should also be ambient, such as nil or low energy requirements and pressure, which leads to an energy-saving procedure. Nanotechnology is an essential aspect of putting the earth on a sustainable path because it combines all of the rewards of the present technology with compact goods that consume minimal energy and resources to run, produce, and integrate the possibility of recycling (Figure 1.6).

1.4 Biosynthesis of Nanoparticles from Plants

Bacteria, fungi, and plants all synthesize different types of nanoparticles [10]. Plants are better suited to the production of nanoparticles (NPs) than bacteria or fungi because metal ion reduction requires less incubation time. Plant tissue culture (PTC) and downstream processing approaches promise to generate metal and oxide NPs on a bigger scale. It has been shown that plants exhibit an innate ability to reduce metals via their particular metabolic pathways [11]. Stampoulis et al. [12] investigated the effects of ZnO, Cu, Si, and Ag NPs on root elongation, seed germination, and biomass production in *Cucurbita pepo* cultivated hydroponically. Compared to the untreated standards, test results showed that root length is reduced by 77% and by 64% when subjected to bulk Cu powder when seedlings are exposed to Cu nanoparticles.