About the Contributors vii

Part I Nanotechnology as a Tool for Sustainability

Chapter 1. Nanotechnology and the Environment
Mark R. Wiesner and Jean-Yves Bottero 3
Nano-convergence and Environmental Engineering 4
Origin and Organization of this Book 6
References 13

Chapter 2. Nanotechnology and Our Energy Challenge
Wade Adams and Amy Myers Jaffe 15
Nanotechnology and Renewable Energy 19
Smalley Electricity Vision 22
Conclusion 24
References 25

Part II Principles and Methods

Chapter 3. Nanomaterials Fabrication
Jean-Pierre Jolivet and Andrew R. Barron 29
Specificity and Requirements in the Fabrication Methods of Nanoparticles 30
Oxides 31
Semiconductor Nanoparticles
(Quantum Dots and Quantum Rods) 58
Metallics, Bimetals, and Alloys 65
Carbon Based Nanomaterials 77
References 97

Chapter 4. Methods for Structural and Chemical Characterization
of Nanomaterials Jérôme Rose, Antoine Thill, and Jonathan Brant 105
Introduction 105
Principles of Light-Material Interactions Atomic Force Microscopy and Scanning Tunnel Microscopy 106
Structural Characterization 107
Surface Physico-Chemical Properties 143
References 152

Chapter 5. Reactive Oxygen Species Generation on Nanoparticulate Material  
Michael Hoffmann, Ernest M. Hotze, and Mark R. Wiesner 155

Background 155
Nanoparticulate Semiconductor Particles and ROS Generation 165
Metal Sulfide Surface Chemistry and Free Radical Generation 182
Fullerene Photochemistry and ROS Generation Potential 185
References 201

Chapter 6. Principles and Procedures to Assess Nanomaterial Toxicity  
Michael Kovochich, Tian Xia, Jimmy Xu, Joanne I. Yeh,  
and André E. Nel 205

Introduction 205
Paradigms for Assessing NM Toxicity 206
Overall Considerations in the Assessment of NM Toxicity 212
Use of Cellular Assays to Study Other Responses that Are Relevant  
to NM Toxicity, Including Cellular Uptake and Subcellular Localization 219
Nanosensors: Sensitive Probes for the Blodetection of ROS 221
Nanoelectrodes 223
Online Data Bank 225
Abbreviations 225
Acknowledgements 226
References 226

Chapter 7 Nanoparticle Transport, Aggregation, and Deposition  
Jonathan Brant, Jérôme Labille, Jean-Yves Bottero,  
and Mark R. Wiesner 231

Introduction 231
Physico-chemical Interactions 232
Aggregation 242
Deposition 257
Nanoparticle Behavior in Heterogeneous Systems 273
Airborne Nanoparticles 285
Summary 288
References 289

Part III Environmental Applications of Nanomaterials

Chapter 8. Nanomaterials for Groundwater Remediation  
Gregory V. Lowry 297

Introduction 297
Reactivity, Fate, and Lifetime 300
Delivery and Transport Issues 311
Targeting 324
Summary and Research Needs 330
List of Acronyms and Symbols 331
References 333
## Chapter 9 Membrane Processes

*Mark R. Wiesner, Andrew R. Barron, and Jérôme Rose*

- Overview of Membrane Processes.................................................338
- Transport Principles for Membrane Processes........................341
- Membrane Fabrication Using Nanomaterials................................356
- Nanoparticle Membrane Reactors.............................................366
- Active Membrane Systems......................................................367
- References..............................................................................367

## Chapter 10 Nanomaterials as Adsorbents

*Mélanie Auffan, Heather J. Shipley, Sujin Yeon, Amy T. Kan, Mason Tomson, Jérôme Rose, and Jean-Yves Bottero*

- Introduction.............................................................................371
- Adsorption at the Oxide Nanoparticles/Solution Interface........372
- Nanomaterial-Based Adsorbents for Water and Wastewater Treatment.................................................................377
- Concluding Remarks................................................................388
- Acknowledgements..................................................................389
- References..............................................................................389

## Part IV Potential Impacts of Nanomaterials

### Chapter 11. Toxicological Impacts of Nanomaterials

*Nancy A. Monteiro-Riviere and Thierry Orsière*

- Introduction.............................................................................395
- Fullerenes................................................................................396
- Single-Walled Carbon Nanotubes (SWCNT)..............................401
- Multi-Walled Carbon Nanotubes (MWCNT).................................403
- Complications in Screening Assays Using Carbon-Based Materials.................................................................405
- Titanium Dioxides....................................................................406
- Iron Oxides................................................................................412
- Cerium Dioxides........................................................................420
- Copper Nanoparticles.................................................................421
- Gold Nanoparticles....................................................................422
- Quantum Dots...........................................................................424
- Exposure and Risk Assessment..................................................431
- Environmental Impact...............................................................433
- Conclusion................................................................................434
- References..............................................................................434

### Chapter 12. Ecotoxicological Impacts of Nanomaterials

*Delina Y. Lyon, Antoine Thill, Jérôme Rose, and Pedro J.J. Alvarez*

- Introduction.............................................................................445
- Why Study the Effects of Nanomaterials on Microorganisms?..........................447
- Methods to Assess Ecotoxicity.....................................................448
- Bioavailability and Cellular Uptake of Nanoparticles................452
- Nanomaterial Interaction with Microbial Cell Components........456
- Antibacterial Activity of Nanomaterials.......................................459
- Biotransformation of Nanomaterials by Microbes.......................466
Acknowledgments

Portions of the work presented in this book were supported by grants from the US National Science Foundation, the US Environmental Protection Agency, and the ECCO-Dyn program of France’s CNRS-FNS. Support from the Office of Science and Technology of the French Consulate (Houston), and Rice’s Environmental and Energy Systems Institute in organizing the symposia that led to this effort are also gratefully acknowledged.
Green nanotechnology refers to the use of nanotechnology to enhance the environmental sustainability of processes producing negative externalities. It also refers to the use of the products of nanotechnology to enhance sustainability. It includes making green nano-products and using nano-products in support of sustainability. Green nanotechnology has been described as the development of clean technologies. Environmental Nanotechnology, Monitoring and Management is a journal devoted to the publication of peer reviewed original research on environmental nanotechnologies, monitoring studies and management for water, soil, waste and human health samples. Critical review articles, short communications and scientific policy briefs are also welcome. The journal will include all environmental matrices except air. Nanotechnology is being promoted as a new generation environmental remediation technology with immense potential to provide cost-effective solutions to many of the most challenging environmental cleanup problems. We invite you to contribute to a special Environmental Science: Nano (ES: Nano) themed issue on Modelling in Environmental Nanotechnology.