



# ENVIRONMENTAL NANOTECHNOLOGY

Applications and Impacts of Nanomaterials

Mark R. Wiesner • Jean-Yves Bottero

# Contents

About the Contributors vii

## Part I Nanotechnology as a Tool for Sustainability

<b>Chapter 1. Nanotechnology and the Environment</b> <i>Mark R. Wiesner and Jean-Yves Bottero</i>	<b>3</b>
Nano-convergence and Environmental Engineering	4
Origin and Organization of this Book	6
References	13
<b>Chapter 2. Nanotechnology and Our Energy Challenge</b> <i>Wade Adams and Amy Myers Jaffe</i>	<b>15</b>
Nanotechnology and Renewable Energy	19
Smalley Electricity Vision	22
Conclusion	24
References	25

## Part II Principles and Methods

<b>Chapter 3. Nanomaterials Fabrication</b> <i>Jean-Pierre Jolivet and Andrew R. Barron</i>	<b>29</b>
Specificity and Requirements in the Fabrication Methods of Nanoparticles	30
Oxides	31
Semiconductor Nanoparticles (Quantum Dots and Quantum Rods)	58
Metallics, Bimetallics, and Alloys	65
Carbon Based Nanomaterials	77
References	97
<b>Chapter 4. Methods for Structural and Chemical Characterization of Nanomaterials</b> <i>Jérôme Rose, Antoine Thill, and Jonathan Brant</i>	<b>105</b>
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
<b>Chapter 5. Reactive Oxygen Species Generation on Nanoparticulate Material</b> <i>Michael Hoffmann, Ernest M. Hotze, and Mark R. Wiesner</i>	<b>155</b>
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
<b>Chapter 6. Principles and Procedures to Assess Nanomaterial Toxicity</b> <i>Michael Kovochich, Tian Xia, Jimmy Xu, Joanne I. Yeh, and André E. Nel</i>	<b>205</b>
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 Biodetection of ROS	221
Nanoelectrodes	223
Online Data Bank	225
Abbreviations	225
Acknowledgements	226
References	226
<b>Chapter 7 Nanoparticle Transport, Aggregation, and Deposition</b> <i>Jonathan Brant, Jérôme Labille, Jean-Yves Bottero, and Mark R. Wiesner</i>	<b>231</b>
Introduction	231
Physico-chemical Interactions	232
Aggregation	242
Deposition	257
Nanoparticle Behavior in Heterogeneous Systems	273
Airborne Nanoparticles	285
Summary	288
References	289
<b>Part III Environmental Applications of Nanomaterials</b>	
<b>Chapter 8. Nanomaterials for Groundwater Remediation</b> <i>Gregory V. Lowry</i>	<b>297</b>
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

<b>Chapter 9 Membrane Processes</b> <i>Mark R. Wiesner, Andrew R. Barron, and Jérôme Rose</i>	<b>337</b>
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
<b>Chapter 10 Nanomaterials as Adsorbants</b> <i>Mélanie Auffan, Heather J. Shipley, Sujin Yean, Amy T. Kan, Mason Tomson, Jérôme Rose, and Jean-Yves Bottero</i>	<b>371</b>
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
<b>Part IV Potential Impacts of Nanomaterials</b>	
<b>Chapter 11. Toxicological Impacts of Nanomaterials</b> <i>Nancy A. Monteiro-Riviere and Thierry Orsière</i>	<b>395</b>
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
<b>Chapter 12. Ecotoxicological Impacts of Nanomaterials</b> <i>Delina Y. Lyon, Antoine Thill, Jérôme Rose, and Pedro J.J. Alvarez</i>	<b>445</b>
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

Factors Mitigating Nanomaterial/Organismal Interactions	468
Summary and Conclusions	471
References	472
<b>Chapter 13. Assessing Life-Cycle Risks of Nanomaterials</b>	
<i>Christine Ogilvie Robichaud, Dickson Tanzil, and Mark R. Wiesner</i>	<b>481</b>
Life-Cycle Impacts and Sustainability	481
First Steps: Risk Assessment from an Insurance Industry Perspective	493
Knowledge Gaps in the Life-Cycle Assessment of Nanomaterials Risks	514
References	522
Index	525

## 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.