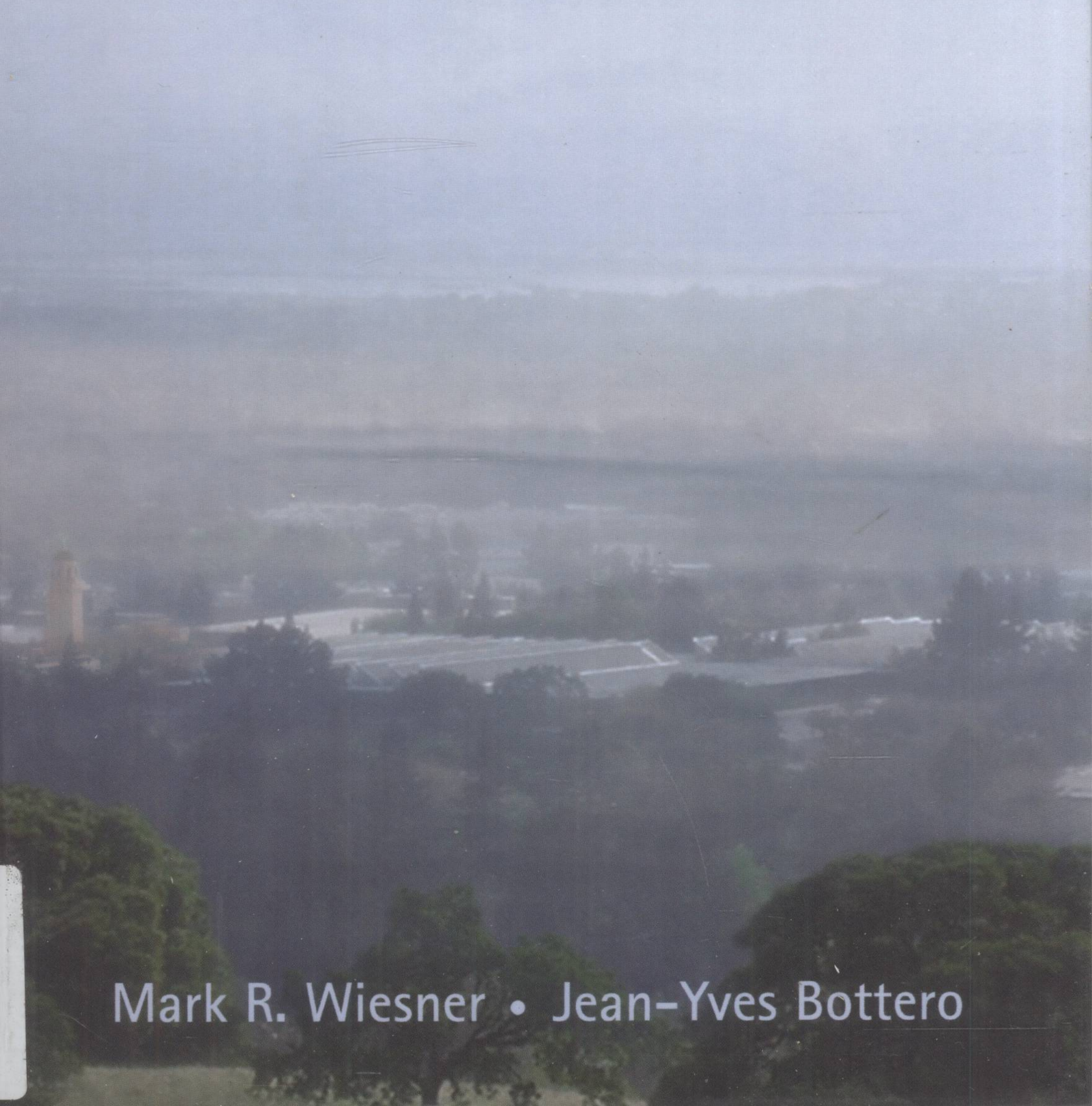
ENVIRONMENTAL NANOTECHNOLOGY

Applications and Impacts of Nanomaterials



Mark R. Wiesner • Jean-Yves Bottero

Environmental Nanotechnology

Applications and Impacts of Nanomaterials

Editors

Mark R. Wiesner, Ph.D., P.E.

Jean-Yves Bottero, Ph.D.

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About the Contributors

Mark R. Wiesner, Ph.D., is a professor of Environmental Engineering at Duke University where he holds the James L. Meriam Chair in Civil and Environmental Engineering. His work has focused on applications of emerging nanomaterials to membrane science and water treatment, and an examination of the fate, transport, and effects of nanomaterials in the environment. Before joining the Duke University faculty in 2006, he served on the Rice University faculty for 18 years in the Departments of Civil and Environmental Engineering and Chemical Engineering, and as director of the Environmental and Energy Systems Institute. He is a co-founder of the Houston-based nanomaterials company Oxane Materials. Dr. Wiesner holds a B.A. in Mathematics and Biology from Coe College, an M.S. in Civil and Environmental Engineering from the University of Iowa, a Ph.D. in Environmental Engineering from the Johns Hopkins University, and has completed postdoctoral training at the École Nationale Supérieure des Industries Chimiques (ENSIC). In 2004, Dr. Wiesner was named a "de Fermat Laureate" and was awarded an International Chair of Excellence at the French Polytechnic Institute in Toulouse.

Dr. Jean-Yves Bottero is a senior research director with France's Centre National de la Recherche Scientifique (CNRS), and director of France's Geoscience and Environment Lab (CEREGE) associated with the University of Paul Cézanne, Aix-Marseille. He also holds an appointment as Adjunct Professor at Duke University. His research addresses physico-chemical phenomena of surfaces and particles. His early work addressed the structure of materials used in water treatment at the nanometric scale, and most notably demonstrated for the first time the existence of the Al_{13} species that controls the chemistry of the now widely used "polyaluminum" coagulants. He has worked extensively on topics ranging from particle aggregation and membrane filtration to solid waste disposal and reuse. More recently, he has been a senior spokesman in Europe in advancing the agenda for research on possible environmental and health impacts of nanomaterials.

Wade Adams, Ph.D., is the director of the Richard E. Smalley Institute for Nanoscale Science and Technology at Rice University. Before heading the Smalley Institute, Dr. Adams was Chief Scientist of the Materials and Manufacturing Directorate, Air Force Research Laboratory, Wright-Patterson Air Force Base, Dayton, Ohio. Dr. Adams was educated at the US Air Force Academy, Vanderbilt University, and the University of Massachusetts. For the past 33 years he has conducted research in polymer physics, concentrating on structure-property relations in high-performance organic materials. He is a Fellow of the American Physical Society and the Air Force Research Laboratory. Dr. Adams retired from the Air Force Reserve in the rank of colonel in 1998.

Pedro J.J. Alvarez, Ph.D., is the George R. Brown Professor and Chair of Civil and Environmental Engineering at Rice University. He received a degree in Civil Engineering from McGill University and M.S. and Ph.D. degrees in Environmental Engineering from the University of Michigan. He is a diplomate of the American Academy of Environmental Engineers and a Fellow of the American Society of Civil Engineers. Honors include being elected president of the Association of Environmental Engineering and Science Professors (2005–2006), the cleanup project of the year award from SERDP (2002), and the Button of the City of Valencia (2000).

Dr. Mélanie Auffan holds a doctoral degree from the University of Paul Cézanne in Aix-Marseille where she performed research at the Geoscience and Environment Lab (CEREGE) on the transport and transformation of manufactured nanoparticles in the environment. Her work addresses cellular interactions of mineral nanoparticle and the use of iron nanoparticles for the adsorption of arsenic.

Andrew R. Barron, Ph.D., is the Charles W. Duncan, Jr.–Welch Chair of Chemistry, Professor of Materials Science, and Associate Dean of Industry Interactions and Technology Transfer at Rice University. Prior to moving to Rice University in 1995 he spent eight years on the faculty at Harvard University. He received his Ph.D. from the Imperial College of Science and Technology, University of London, and served as a post-doctoral research associate at the University of Texas. Dr. Barron currently sits on the editorial boards of three chemistry and materials science journals, is a Fellow of the Royal Society of Chemistry, and is the 1997 recipient of the Humboldt Senior Service Award.

Jonathan Brant, Ph.D., is a research associate at Duke University in the Department of Civil and Environmental Engineering. He obtained a Ph.D. in environmental engineering at the University of Nevada, Reno, where his research focused on the characterization of interfacial interactions between water-treatment membranes and organic and inorganic materials with the purpose of reducing fouling. Upon completion of his Ph.D. he completed a two-year postdoctoral research assignment at Rice University where he studied the behavior of fullerene nanomaterials in environmental systems. His areas of research focus on characterizing surfaces to predict and understand the impact of materials in environmental processes.

Michael Hoffmann, Ph.D., received a B.A. in chemistry from Northwestern University and a Ph.D. in chemical kinetics from Brown University. In 1973, he was awarded an NIH postdoctoral training fellowship in Environmental Engineering Science at the California Institute of Technology. From 1975 to 1980, he was member of the faculty at the University of Minnesota and since 1980 a member of the faculty at Caltech (Engineering and Applied Science). Dr. Hoffmann has published more than 220 peer-reviewed professional papers and is the holder of seven patents. In 2001, Dr. Hoffmann was presented with the American Chemical Society Award for Creative Advances in Environmental Science and Technology and received the Jack E. McKee Medal for Groundwater Protection by the Water Environment Federation in October 2003.

Ernest (Matt) Hotze is a doctoral candidate at Duke University where he is performing research on Reactive Oxygen Production by nanoparticles. He holds an M.S. in Environmental Engineering from Rice University and a B.S. in Chemistry from Notre Dame.

Amy Myers Jaffe is the Wallace S. Wilson Fellow in Energy Studies at the James A. Baker III Institute for Public Policy and associate director of the Rice University energy program. Her research focuses on the subject of oil geopolitics, strategic energy policy including energy science policy and energy economics. Ms. Jaffe is widely published in academic journals and numerous book volumes and served as coeditor of *Energy in the Caspian Region: Present and Future* (Palgrave, 2002) and *Natural Gas and Geopolitics: From 1970 to 2040* (Cambridge University Press, 2006). She served as a member of the reconstruction and economy working group of the Baker/Hamilton Iraq Study Group, and as project director for the Baker Institute/Council on Foreign Relations task force on Strategic Energy Policy.

Dr. Jean-Pierre Jolivet is a professor at the Université Pierre et Marie Curie (Paris 6), in Paris, France, where he teaches inorganic chemistry. His research activities are focused on the synthesis of metal and metal oxide nanoparticles with controlled characteristics (crystalline structure, morphology, size, and dispersion state in various solid or liquid media) for various application areas such as optics, electrochemistry, catalysis, and nanomagnetism. He is equally involved in research addressing the environmental impact of nanomaterials. He is the author of a widely cited book, *Metal Oxide Chemistry and Synthesis: From Solution to Solid State.*

Dr. Jérôme Labille is a researcher with the French National Research Center (CNRS) at the Geosciences and Environment Lab (CEREGE). He obtained a Ph.D. in physical chemistry of Geosciences in the French Institute INPL and did subsequent postdoctoral work at the Analytical Center for Biophysicochemistry of the Environment (CABE) in Geneva. He has been working at CEREGE for three years on the environmental fate of manufactured nanoparticles, considering and characterizing the numerous conditions that control their bioavailability and toxicity, such as surface reactivity, colloidal dispersion, and interaction with organics or pollutants.

Gregory V. Lowry, Ph.D., is an associate professor of Environmental Engineering at Carnegie Mellon University in Pittsburgh, Pennsylvania. His research interests are broadly defined as transport and reaction in porous media, with a focus on the fundamental physical/geochemical processes affecting the fate of inorganic and synthetic organic contaminants and engineered nanomaterials in the environment. He is an experimentalist and works on a variety of application-oriented research projects developing novel environmental technologies for restoring contaminated sediments and groundwater, including reactive nanoparticles for efficient *in situ* remediation of entrapped NAPL and innovative sediment caps for *in situ* treatment and management of PCB-contaminated sediments.

Delina Y. Lyon is a doctoral student in the Civil and Environmental Engineering Department at Rice University. She received a B.A. from St. Mary's College of Maryland and an M.S. in Microbiology from the University of Georgia.

Nancy Ann Monteiro-Riviere, Ph.D., is a Professor of Investigative Dermatology and Toxicology at the Center for Chemical Toxicology Research and Pharmacokinetics, North Carolina State University (NCSU), a professor in the Joint NCSU/UNC-Chapel Hill Biomedical Engineering Faculty, and Research Adjunct Professor of Dermatology at the School of Medicine at UNC Chapel Hill. Dr. Monteiro-Riviere received an M.S. and Ph.D. from Purdue University. She completed postdoctoral training at Chemical Industry Institute of Toxicology in Research Triangle Park, North Carolina. Dr. Monteiro-Riviere was president of the Dermal Toxicology and In Vitro Toxicology Specialty Sections of the National Society of Toxicology and currently serves as chairperson of the Board of Publications. She is a Fellow in the Academy of Toxicological Sciences and in the American College of Toxicology.

André E. Nel, M.D., Ph.D. is a Professor of Medicine and Chief of the Division of NanoMedicine at UCLA. He runs the Cellular Immunology Activation Laboratory in the Johnson Cancer Center at UCLA. Dr. Nel obtained his M.B., Ch.B. (M.D.), and Doctorate of Medicine (Ph.D. equivalent) degrees from the University of Stellenbosch in Cape Town, South Africa, and subsequently did Clinical Immunology and Allergy training at UCLA. Dr. Nel is the principal investigator of the UCLA Asthma and Immunology Disease Center, codirector of the Southern California Particle Center, and director of the University of California Nanotoxicology Research and Training program. He served as chair of the Allergy Immunology Transplant Research Committee at the NIAID and is chair of the Air Pollution Committee in the AAAAI. Dr. Nel is a member of the ASCI, AAAAI, AAI, and the Western Association of Physicians.

Dr. Christine Ogilvie Robichaud is a doctoral candidate at Duke University where she is engaged in research on assessing life-cycle risks of nanomaterials, targeting use in energy technologies. Ms. Robichaud holds an M.S. in Environmental Analysis and Decision Making from Rice University, and a B.S. in Industrial Engineering from Texas A&M University. Prior to graduate school she worked in energy supply chain consulting and in the biofuels industry.

Dr. Thierry Orsière has been a Research Scientist at the Université de la Méditerranée (Faculty of Medicine) since 1996. He obtained a Master's degree in Biochemistry from the Université de Provence (Aix-Marseille) and a doctorate of Pharmacology from the Université de la Méditerranée (Aix-Marseille). His research has focused on the effects of DNA damage and changes in processes governing cell division on human cells. His work has included studies of worker exposure to mutagens, determination of the ability of contaminants to induce chromosome aberrations, and the genotoxic properties of mineral nanoparticles.

Dr. Jérôme Rose is a senior scientist at the CEREGE (CNRS) since 1997 and serves as adjunct faculty at Rice University and Columbia University. He obtained an Engineering degree in geosciences and a doctorate from the Lorraine National Polytechnic Institute (France). He has supervised twelve Ph.D. students and two postdoctoral researchers. Dr. Rose was the 2006 recipient of the bronze medal from the CNRS. His research focuses on the behavior and toxicity of colloids and contaminants from laboratory to field scale. He is employing intensively synchrotron-based techniques to study mechanisms at a molecular level.

Dr. Rose has been involved in research on the environmental impact of nanotechnology since at least 2001 and is one of the inventors of the ferroxane nanoparticles.

Heather J. Shipley is a Ph.D. candidate at Rice University working on arsenic adsorption with iron oxide nanoparticles. She also has done research with the Brine Chemistry Consortium at Rice University on iron sulfides and inhibitor adsorption. Previously, she conducted research with the Hazardous Substance Research Center South/Southwest on the resuspension of sediments to predict the amount of metals that can become available. Ms. Shipley holds a B.S. degree in chemistry from Baylor University, Waco, Texas. and an M.S. in Environmental Engineering from Rice University.

Dicksen Tanzil, Ph.D., is a sustainability specialist at Golder Associates Inc. He received his doctorate from Rice University and B.S. from Purdue University, both in chemical engineering. His work focuses on the assessment of environmental and social impacts of industrial operations, and the incorporation of sustainability considerations in engineering design and business decision-making. He is co-editor of the book *Transforming Sustainability Strategy into Action: The Chemical Industry*, published in 2005.

Dr. Antoine Thill is a researcher at the Commissariat de l'Energy Atomique in Saclay (Paris) where he is in charge of the Ultra Small Angle X-ray Scattering facility at the Laboratoire Interdisciplinaire sur l'Organisation Nanométrique et Supramoléculaire in the Department of Material Science. He holds a doctorate in Geosciences and Engineering from the University of Aix-Marseille III where he studied the aggregation of natural suspended matter in estuaries and developed methods to characterize particle size and agglomeration states by light scattering and confocal microscopy. His work addresses the structure and dynamics of nanoparticles in complex samples through an intensive use of scattering techniques as well as a consideration of properties of these particles as they affect bacterial toxicity of CeO_2 and other nanoparticles.

Joanne I. Yeh, Ph.D., obtained her Ph.D. in 1994 from the Chemistry Department at the University of California, Berkeley, where she studied macromolecular X-ray crystallography as a NSF predoctoral fellow under the supervision of Professor Sung-Hou Kim. Dr. Yeh was a NIH post doctoral fellow with Professor Wim G.J. Hol at the University of Washington/Howard Hughes Medical Institute, studying through structural characterization soluble and membrane proteins involved in oxidative and glycerol metabolism pathways.

Contents

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Part

I

Nanotechnology as a Tool for Sustainability

Chapter

1

Nanotechnology and the Environment

Mark R. Wiesner *Duke University, Durham, NC*

Jean-Yves Bottero *CNRS-University of Aix-Marseille, Aix-en-Provence, France*

Advances in information technologies, materials science, biotechnology, energy engineering, and many other disciplines—including environmental engineering—are converging at the quantum and molecular scales. This molecular terrain is common ground for interdisciplinary research and education that will be an essential component of science and engineering in the future. Much like the digital computer and its impact on science and technology in the 20th century, the tools that serve as portals to the molecular realm will act as both instruments of discovery and rallying points for social interaction between researchers from many disciplines. In this setting, environmental engineers and scientists will take on new roles in collaborating with materials scientists, molecular biologists, chemists, and others to address the challenges of meeting society's needs for energy and materials in an environmentally responsible fashion.

Nanotechnology is defined as a branch of engineering that deals with creating objects smaller than 100 nm in dimension. Behind this definition is a vision of building objects atom by atom, molecule by molecule [1] by self-assembly or molecular assemblers [2]. Activities spawned by a "nanomotivated" interdisciplinarity will affect the social, economic, and environmental dimensions of our world, often in ways that are entirely unanticipated. We focus here on the potential impacts of nanomaterials on human health and environment. Many of these impacts will be beneficial. In addition to a myriad of developments in medical science, there is considerable effort underway to explore uses of nanomaterials in applications such as membrane separations, catalysis, adsorption, and analysis with the goal of better protecting environmental quality.

However, along with these innovations and the growth of a supporting nanomaterials industry, there is also the need to consider impacts of nanomaterials on environment and human health. Past technological accomplishments such as the development of nuclear power, genetically modified organisms, information technologies and synthetic organic chemistry have generated public cynicism as some of the consequences of these technologies, often environmental, become apparent. Even potable water disinfection, the single most important technological advance with regard to prolonging human life expectancy, has been found to produce carcinogenic by-products. Some groups have called on industry and governments to employ the precautionary principle while conducting more research in toxicology and transport behaviors [3, 4]. The precautionary principle, often associated with the Western European approach to regulation, might be summarized as "no data, no market." In contrast, the risk-based approach that has come to typify regulatory development in the United States, might be reduced to the philosophy of "no data, no regulation." Both approaches require reliable data. Although studies are beginning to appear in the literature addressing the toxicity of various nanomaterials [5–10] and their potential for exposure [11, 12], at this stage definitive statements regarding the impacts of nanomaterials on human health and the environment remain sketchy.

In this book, we consider the topic of nanomaterials through the lens of environmental engineering. A key premise of our approach is that the nanomaterials industry is an emerging case study on the design of an industry as an environmentally beneficial system throughout the life cycle of materials production, use, disposal, and reuse. One element of this socio-industrial design process is an expansion of the training and practice of environmental engineering to include concepts of energy and materials production and use into environmental engineering education and research.

Nanoconvergence and Environmental Engineering

Environmental engineering evolved from an interdisciplinary approach to solving water quality problems that traces its origins to the latter part of the 19th century. The concept of bringing microbiologists, stream ecologists, traditional civil engineers, and aquatic chemists together to resolve problems with dissolved oxygen in surface water originating from waste discharges was revolutionary in its time. This interdisciplinary