Guest Comment

Nanoscale environmental science and technology: Challenges and opportunities

In his now legendary December 20, 1959, lecture *Plenty of Room at the Bottom*, physicist Richard P. Feynman spoke of the possibilities associated with the nascent field of nanotechnology, foreshadowing the revolution that was to come decades later. The visionary Feynman said, "I would like to describe a field in which little has been done but in which an enormous amount can be done in principle. What I want to talk about is the problem of manipulating and controlling things on a small scale. . . . Atoms on a small scale behave like *nothing* on a large scale, for they satisfy the laws of quantum mechanics. At the atomic level, we have new kinds of forces and new kinds of possibilities, new kinds of effects" (www.its.caltech.edu/%7Efeynman/plenty.html).

Today, Feynman's dream is surely being realized on a grand and global scale. The technical and popular literature is chock-full of discoveries of novel physical, chemical, and biological properties associated with materials whose dimensions are in the nanoscale domain (1–100 nm). Currently, more than 475 nanotechnology products, including tennis rackets, pants, beer bottles, and precision instruments for manufacture and observation of nanomaterials, are available in the U.S. market.

Insofar as environmental applications are concerned, nanomaterials offer the promise of novel materials and processes exhibiting enhanced reactivity toward targeted contaminants, better mobility in environmental media, and easier deployment. As shown in this special issue, many nanoenvironmental technologies (e.g., sensors, sorbents, and reactants) are currently under active research and development and are expected to play a leading role in the next generation of environmental technologies. Taken together, they have the potential to significantly improve and advance the current state of the art.

Nanotechnology also offers indirect applications to pollution prevention through improved catalytic processes that produce less waste, better sensors for process controls, enhanced separations, and increased understanding of the nanoscale natural processes that inform industrial processes. Applying the principles of green engineering and green chemistry to the production of nanomaterials and their end products is another indirect way that nanotechnology aids the environment.

In a broader sense, nanoscale science and technology have definite social, economic, environmental, and ethical dimensions that could dramatically change the world in which we live. According to data collected by the U.S. National Nanotechnology Initiative (NNI), the quantity of manufactured nanoscale materials and products is growing rapidly. During the next 10–15 years, nanotechnology sectors are expected to exceed $1 trillion annually in global industrial output and to employ about 2 million workers (www.nano.gov/html/res/IntlFundingRoco.htm).

An inevitable consequence of this rapid growth is the eventual exposure of humans and other environmental receptors to nanoscale materials. Little is currently known about the fate, transport, and transformation of nanosized materials once they enter the environment, although there is an increasing amount of research on the toxicology of nanomaterials. As the production of manufactured nanomaterials increases and as products containing nanomaterials are disposed of, unintended and deleterious repercussions from these activities may result. These potentially harmful effects may be attributable to the nature or behavior of the nanoparticles themselves, the characteristics of the products made from them, or aspects of the manufacturing process. The large surface area, crystalline structure, and enhanced reactivity may cause certain engineered materials to be considered a new class of toxins. Because of concerns about the possible risks of nanotechnology and nanomaterials, research is being carried out in the areas of human and ecotoxicology, as well as exposure throughout a nanoproduct life cycle.

Challenges also exist to introducing nanoscale science and technology to the next generation of environmental scientists and engineers. For nanoscale environmental science and engineering concepts to be conveyed effectively, new resources must be used to upgrade laboratories and develop textbooks and other teaching tools. A variety of interdisciplinary approaches will be needed to integrate

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nanoscale environmental science and technology into existing curricula, particularly at the undergraduate level. Environmental scientists and engineers should also play a leading role in fostering public awareness and understanding of nanoscale science, engineering, and technology.

Over the past few years, U.S. research funding for environmental science and technology has been reduced substantially in some agencies and has remained stagnant at best for others. In contrast, investment in nanoscale science and technology has experienced significant growth. For example, funding for the multi-agency NNI doubled from 2001 to 2004 (to about $1 billion in 2005). Nanotechnology investment by the business community and state and local governments has similarly grown. In 2004, agencies participating in the NNI funded an estimated $106 million in research on the health and environmental aspects of nanoscale materials. Globally, nanotechnology research and development investment has increased approximately 7-fold, from $432 million in 1997 to about $3 billion in 2003 (www.nano.gov/html/res/IntlFundingRoco.htm). At least 30 countries have initiated national activities in this field. Many of these countries are including research targeted at both applications to and implications for the environment. Thus, it appears that funding in this critical area is increasingly becoming an important source for environmental research and development.

We would like to thank Jerald Schnoor and Alan Newman for this opportunity and for their encouragement throughout the process. This special issue wouldn't have been possible without the talents and dedication of Barbara Booth. Finally, we sincerely thank all the reviewers for the time and effort they contributed to make this a reality. We hope that this special issue will serve as a timely catalyst for spurring additional exciting advances in education, research, and applications of nanoscale science and technology for the benefit of our environment.

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Guest Editors for the Nanotechnology Special Issue

Two editors selected manuscripts for consideration and managed the review process for the papers in this issue of *ES&T*.

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