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EDITORIAL

Nanotechnology: promoting innovation through analysis and governance

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While risk assessment has been a primary mechanism for assessing how to protect human and environmental health from engineered materials, data gaps and general inexperience with nanomaterials have resulted in its limitations to taking up this emerging technology. The difficulty in assessing the largely uncharacterized risks that nanomaterials pose can potentially stall the emergence of otherwise high-performing materials out of consideration of those risks (Matus et al. 2011). As nanotechnology continues to outpace regulation, researchers seek unconventional tools to guide the deployment of nano-enabled materials, so that the great promises of the novel materials can be realized in a responsible manner (Linkov et al. 2009).

Despite the challenge of developing regulations to rein in the emergence of nanotechnology, the industry is uniquely positioned to explicitly minimize the overall risks and externalities of their technologies during the material and product design phase. Unlike traditional materials and technologies, in which risk is inherent to their material properties and cannot be significantly changed by technological processes, nanomaterials are engineered. The material design phase is a unique leverage point in creating green nanomaterials; those material characteristics that lead to potential environmental and health risks can be changed up front instead of mitigated at some later time. For the nanotechnology community, this could effectively mean a new approach, from “What harm might this designed material cause?” to “How can we adjust the design of this ’material to minimize the harm it will cause?” This shift could help operationalize the underutilized guidance offered by green chemistry and green engineering principles (Anastas and Warner 1998; Anastas and Zimmerman 2003).

Shifting away from material functionality as the sole design goal, however, requires the ability to make choices in a much more complex decision space. Decisions based on the full life-cycle risks of nano-enabled products must incorporate cost, exposure, safety, persistence, and mobility as well as qualitative information such as stakeholder input and value judgments. For this Special Issue of ESD, we invited research papers that respond to the urgent need for a proactive approach to nanomaterial risk management, including weighing the benefits and risks of new nanotechnologies.

A common theme of the papers in this issue is the need to understanding the risks and impacts of nanomaterials and nanoproducts in order to realize their numerous and enormous benefits. Many authors posit that we can overcome the data gaps that impede traditional assessment of risk by using expert judgment in its place, but most of them point out that expert judgment may be a major source of uncertainties. The tool proposed by Grieger et al. (2015) offers ways to communicate uncertainties stemming from expert elicitation, making it suitable for screening-level risk investigations. It compares the risks of nanomaterials based on both quantitative and qualitative information and can also help prioritize future investigations. This tool fits in the risk screening framework for nanomaterials proposed by

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Beaudrie et al. (2015). They detail the main outcome of a Structured Decision Making workshop that drew upon expertise in nanotoxicology, exposure, environmental fate and transport, and structured decision making. Expert judgment is also the focus of Powers et al. (2015), who propose the use of data dialogs to facilitate discussions between the environmental health and safety research community and decision makers. The authors examine the importance of these structured discussions in the context of several research barriers, potential solutions, and incentives to help implement these or other solutions in order to support a broader dialog about solving the limitations in the risk assessment of nanomaterials. Isaacs et al. (2015) add to this discussion with their summary of the 2014 annual meeting of the Sustainable Nanotechnology Organization (SNO) and conclude that there remains untapped potential in broad stakeholder participation to guide the emergence and governance of nanotechnology.

Stakeholder participation is a key topic in the paper by Malsch et al. (2015). The authors recognize that achieving safe and sustainable nanomanufacturing requires understanding of how stakeholders view the risk management of nanomaterials. They seek to understand the tools currently used by stakeholders as a source of capabilities and propose their adaptation into a decision support system. One important group of stakeholders in this respect is regulators.

Two papers in particular address how planning over the life cycle of nano-enabled materials can aid the industry in sustainability planning. Subramanian et al. (2015) affirm that multi-criterial decision analysis can effectively provide the structural scaffold, mathematical techniques, and domain knowledge to integrate risk assessment and life-cycle analysis into a common framework to achieve environmental and social objectives of nanotechnology in addition to economic ones. Wigger et al. (2015) are concerned with sustainable material management and contend that, through planning, we can use nano-enabling materials more sustainably.

Papers presented in this Special Issue and our past work further illustrate the need for a *top-down approach* in nanomaterial design that can effectively integrate industry's material performance and financial objectives while explicitly considering overall risks and externalities of their technologies. There is a suite of *top-down* decision analysis tools available which could be employed during the material design phase to integrate a broad array of life-cycle impact considerations and deliberately minimize the negative externalities of new nanomaterials before they emerge into commercial use (Linkov et al. 2014).

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