Current Prospective on Environmental Nanotechnology Research in China

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China is now a global leader in nanomaterial manufacturing. For example, according to a market research firm IDTechEx, China now has close to 70 percent of the nominal global production capacity for graphene (at hundreds of tons level). Driven by government-led incentives and expected market demand, R&D spending in nano-related fields has rapidly increased. Out of all such spending, about 7% was allocated to study environmental, health and safety implications of nanotechnology,[1] which did not yet include the portion for developing novel environmental applications. Taken together, China and the United States account for the majority of the publications on environmental nanotechnology, as observed in high-impact, field-related peer-reviewed journals, including *Environmental Science & Technology*. Despite these significant developments, an overall, coherent picture of major research initiatives and outcomes in China is unclear from the perspective of the international research community. Here, we provide a topical perspective with the goal of better understanding China's contributions and future research strategies regarding the nanomaterial-environmental nexus.

Overall, current research on environmental nanotechnology is closely connected to China's social and economic development goals - from the precautionary investigation of environmental and health effects of nanomaterials that it manufactures, to the control of water, soil and air pollutions that are currently widespread in the country. Related progress will be presented in the three following aspects: technologies to address environmental challenges; transformation processes and ecological fate; and biological exposure and health implications of nanomaterials.

Over the past three decades, the environmental nanotechnology research communities have seen the emergence of various nanomaterials, from fullerenes, carbon nanotubes, metal (oxide) nanoparticles, to graphene, and more recently, other 2D materials and metal organic frameworks, among others. The incorporation of novel nanomaterials has significantly improved conventional treatment processes including adsorption, membrane separation, and catalysis. Chinese researchers have been actively involved in the development of a number of technologies such as catalysis and adsorption, and have made progress towards scaled-up production and field applications. Severe water pollution has opened the door for exploring the use of novel remediation technologies. For instance, novel composites that incorporate iron oxide nanoparticles in millimeter-sized polystyrene spheres are being used in meter-scale reactors to decontaminate tanning, electroplating, and mining wastewaters.[2] Also, a new type of graphene-TiO_2 based photocatalytic nets is under large-scale evaluation for *in-situ* cleanup of contaminated rivers (Shuang-liang Photocatalysis). The motivation for such translational research has been largely driven by the government's ambitious campaign to clean up about 2,100 urban "black and stinky waterways" by 2030. While this ambitious exploration is worthy of debate considering the potential release and risks of these nanocatalysts in ecosystems, it does underscore the social, economic, and especially political forces that are driving China's rapidly increasing R&D industry. This also suggests that Chinese researchers will have to work closely (and urgently) with regulators to develop a legal framework that can provide safe, sustainable pathways for rapid development and deployment of nanotechnologies.

Research regarding environmental implications of nanotechnology has also been a highly active area, in line with the emergence of various nanomaterials. Among all such research, carbon and metal nanomaterials have been the primary focus to date – China is likely to be the largest manufacturer (and maybe consumer) in the years to come. To detect these nanomaterials in complicated environmental matrixes remains a significant challenge; however, interesting progress has been made. For example, a new approach was developed to investigate chemical transformations of Ag NPs based on natural isotopic ratios (*e.g.,* ^{107}Ag and ^{109}Ag).[3] Looking forward, bridging knowledge obtained in laboratory settings with the real environmental sampling will become an important research direction. The release and exposure in high-concentration scenarios such as manufacturing should become a priority area of study. It provides a venue to test new detection methods, apply precautionary/mitigation measures, investigate health effects, and so forth.

Another major area of research focus is the potential impact of material exposure on human health. Studies have ranged from molecular-level mechanisms, particle-level modelling, to macro-level effects. For example, the toxicity mechanism(s) of graphene has been under debate, but its molecular interactions offer new insights into cellular/molecular effects upon its exposure. Graphene oxide was found to interact and consequently suppress the expression of integrin on the plasma membrane, which results in a subsequent cellular priming state.[4] This type of studies represents routes for the development of adverse outcome pathways that eventually determine the toxicity and health risks. Such fundamental knowledge is critical as it facilitates the development of 'safe-by-design' nanomaterials, and potentially guides local manufacturing practices and beyond, including disposal. Also, particle-level modelling was used to interpret possible health effects of airborne fine particulates. For example, a study shows hydrophilic nanoparticles generally translocate quickly across the pulmonary surfactant film, but a significant portion of hydrophobic nanoparticles are trapped and encapsulated in lipid protrusions upon film compression.[5]

The remarkable pace at which environmental nanotechnology has developed is matched by China's own advances in both nanoscience and environmental chemistry. Nanotechnology is a priority in China's National Key R&D Program, with Environmental Nanotechnology being one of the seven focus areas. The Natural Science Foundation of China (NSFC) has also supported several major research projects focusing on nanotechnology for water and soil pollution control (analogous to the US NSF Engineering Research Center). In the near term, environmental nanotechnology research in China will continue to address local, tough environmental challenges, in accordance with the government's three major campaigns against water, air and soil pollution. With this support, Chinese researchers will also contribute fundamental knowledge to the global research community.

Over a longer time scale, the scope of environmental nanotechnology research in China will expand, becoming even more cross-disciplinary. While much has been accomplished with regard to applications and implications, most has been focused on water and then soil; more will be done in air and at the interfaces between water, soil, and air. Environmental nanotechnology research also has a broad interface with nanotechnologies for energy, agriculture, and so on. Like many other branches of environmental research, the research scope for environmental nanotechnology is also likely to increase to support these major interrelated pillars of sustainable development in the long run. To summarize, in anticipation of China's rising nano-manufacturing capabilities and lasting enormous environmental challenges, the much needed research fields will continue to grow at a fast pace, and more exciting opportunities will also come for collaborations across both the academic and geographical boundaries.

References

1. Springer Nature; National Center for Nanoscience and Technology of China; National Science Library of the Chinese Academy of Sciences (CAS) *Small science in big China - An overview of the state of Chinese nanoscience and technology*; 2017.
2. Zhang, X. L.; Cheng, C.; Qian, J. S.; Lu, Z. D.; Pan, S. Y.; Pan, B. C., Highly Efficient Water Decontamination by Using Sub-10 nm FeOOH Confined within Millimeter-Sized Mesoporous Polystyrene Beads. *Environ. Sci. Technol.* **2017,** *51*, (16), 9210-9218.
3. Lu, D. W.; Liu, Q.; Zhang, T. Y.; Cai, Y.; Yin, Y. G.; Jiang, G. B., Stable Silver Isotope Fractionation in the Natural Transformation Process of Silver Nanoparticles. *Nat. Nanotechnol.* **2016,** *11*, (8), 682-686.
4. Zhu, J. Q.; Xu, M.; Gao, M.; Zhang, Z. H.; Xu, Y.; Xia, T.; Liu, S. J., Graphene Oxide Induced Perturbation to Plasma Membrane and Cytoskeletal Meshwork Sensitize Cancer Cells to Chemotherapeutic Agents. *ACS Nano* **2017,** *11*, (3), 2637-2651.
5. Hu, G. Q.; Jiao, B.; Shi, X. H..; Valle, R. P.; Fan, Q. H.; Zuo, Y. Y., Physicochemical Properties of Nanoparticles Regulate Translocation across Pulmonary Surfactant Monolayer and Formation of Lipoprotein Corona. *ACS Nano* **2013,** *7*, (12), 10525-10533.