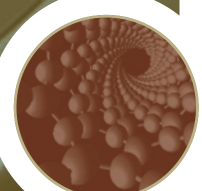
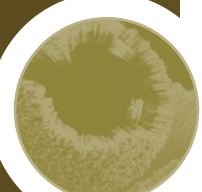
Woodrow Wilson International Center for Scholars
Project on Emerging Nanotechnologies

WHERE DOES THE NANO GO?

End-of-Life Regulation of Nanotechnologies

Linda K. Breggin
John Pendergrass





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CONTENTS

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About the Authors

Linda K. Breggin joined the Environmental Law Institute (ELI) in 1997 as a Senior Attorney. She is also Director of Southeast Environmental Programs for the Institute and directs its Nanotechnology Initiative. Ms. Breggin previously served as an Associate Director in the White House Office on Environmental Policy and as a Special Assistant to the Assistant Administrator for Enforcement at the U.S. Environmental Protection Agency. Prior to joining ELI, she was in private practice. Ms. Breggin has worked on a wide range of environmental law issues over the past 18 years. She is the author or co-author of numerous reports and articles, including a recent article in the *Columbia Journal of Environmental Law* entitled "Governing Uncertainty: The Nanotechnology Environmental, Health, and Safety Challenge" and an ELI report on a dialogue convened in 2005 entitled *Securing the Promise of Nanotechnology: Is U.S. Environmental Law Up to the Job?* Ms. Breggin is a graduate of the University of Chicago Law School. She formerly served as Co-Chair of the District of Columbia Bar Association's Section on Environment and Natural Resources and as a Vice Chair of the American Bar Association's Section of Environment, Energy and Resources, Committee on Innovation, Management Systems and Trading.

John Pendergrass has more than 25 years' experience in environmental and natural resource law. He joined the Environmental Law Institute in 1988 as a Senior Attorney and is the Director of ELI's Center for State, Local, and Regional Environmental Programs. He has conducted numerous studies of state environmental programs and has written extensively about state programs and the state-federal relationship. His research and writing have covered a variety of topics, including hazardous waste, water quality, property law and the public trust doctrine, land use, Superfund, state hazardous substance cleanup programs, brownfields, institutional controls, pollution prevention, biodiversity protection, enforcement, environmental management systems, market-based environmental programs, international environmental law, and sustainable development. He is the author of more than 20 articles and book chapters. Before joining ELI, Mr. Pendergrass was a Visiting Assistant Professor at the Illinois Institute of Technology, Chicago-Kent College of Law, an Associate with the firm of DeWitt, Sundby, Huggett, Schumacher & Morgan, S.C. in Madison, Wisconsin, and an Attorney-Advisor in the Office of the Solicitor of the U.S. Department of the Interior. He has a J.D. degree from Case Western Reserve University and a B.S. degree in environmental science from Michigan State University.

The **Environmental Law Institute** makes law work for people, places, and the planet. With its non-partisan, independent approach, ELI promotes solutions to tough environmental problems. The Institute's unparalleled research and highly respected publications inform the public debate and build the institutions needed to advance sustainable development.

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Preface

Thinking about the long-term implications of nanotechnology—the ability to observe and manipulate matter at the nanoscale—requires a better understanding of how this technology will impact the oversight system at various stages of the regulatory process. Today, with over 500 nano-enabled products already on the market, one of the questions in greatest need of attention is how various forms of nanomaterials will be disposed of and treated at the end of their use. They may find their way into landfills or incinerators, and, eventually, into the air, soil, or water bodies. As we are learning, when we throw something away, there really is no "away."

A number of organizations, including the Royal Society in England, have emphasized the need to take a life-cycle approach to nanotechnology oversight, which covers nanomaterials from their production through use and eventual disposal. Though there is significant conceptual agreement on this approach, the details of how to implement life-cycle approaches have not been adequately addressed, nor have existing laws been adequately analyzed. This report by Linda Breggin and John Pendergrass of the Environmental Law Institute is the most comprehensive analysis done to date of two key EPA-administered laws that regulate the end-of-life strategies for materials and products: the Resource Conservation and Recovery Act (RCRA), and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as the Superfund statute.

Of key importance is answering the question: Will regulation designed to deal with end-of-life issues work for nanotechnology? If not, regulators will need to determine what must be done to provide adequate levels of protection for humans and ecosystems. The report addresses this question in two ways: first, by thoroughly analyzing these laws and their applicability to nanotechnology; and, second, by applying this analysis to two hypothetical companies, to provide a sense of how stakeholders involved in commercializing nanotechnology might be affected by such regulations.

The report highlights the importance of resolving questions regarding regulatory applicability and adequacy to provide clear guidance to industry and to avoid significant long-term liabilities for businesses, insurers, and investors. EPA must decide how RCRA and CERCLA apply in different situations and with respect to different types of nanomaterials. Companies that manufacture and transport nanomaterials must understand and focus on these statutes as part of their environmental due diligence, reporting, and planning processes. Finally, investors and insurers must consider potential nanotechnology environmental risks and liabilities as part of their investment and holding portfolios. This report provides a comprehensive review of material disposal legislation to help ensure that end-of-life regulatory decisions are considered early in the development of nanotechnology.

– David Rejeski
Director, Project on Emerging Nanotechnologies

Executive Summary

Nanotechnology—the ability to observe and engineer matter within the general size range of 1 to 100 nanometers—is creating a set of materials that have properties that differ in fundamental ways from those of larger forms of the same material, and that make them useful for a variety of applications. It is estimated that there are more than 500 nanotechnology consumer products, as well as increasing numbers of industrial products, already on the market. These products eventually will reach the end of their useful lives and be discarded. In addition, waste materials are being generated during the manufacture of nanotechnology products. Some of the wastes from nanotechnology manufacturing are and will be conventional, but others will include nanomaterials in the waste stream, whether entering a landfill, incinerator, or other end-of-life scenarios. This report uses two hypothetical case studies based on current experience to examine how nanowastes could be regulated under existing federal laws.

The Laws: RCRA and CERCLA

The two federal laws that specifically cover wastes and end-of-life issues are the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, or the Superfund law). RCRA regulates the handling, reuse, recycling, storage, treatment, and disposal of solid wastes, including hazardous wastes. CERCLA was enacted to address hazardous substance contamination that the regulatory system had failed to address prospectively through other laws, including RCRA.

This report concludes that RCRA and its implementing regulations cover nanowastes, although the focus of the statute and regulations on mass as a determinant of regulatory coverage is not necessarily appropriate for nanowastes. Moreover, disposal of most consumer products containing nanomaterials is likely to be exempt from the hazardous waste regulations because such products will be considered as household waste. Some waste nanomaterials likely will be classified as hazardous wastes under the existing rules, either as listed hazardous wastes or under the toxicity characteristic. Research is needed to determine whether existing practices for handling, treating, storing, and disposing of bulk forms of solid wastes are appropriate for nanoscale wastes of the same chemicals. Many generators of nanowastes may have insufficient information to provide to owners or operators of treatment, storage, and disposal facilities to enable them to manage such wastes appropriately. Finally, the authority for the Environmental Protection Agency (EPA) and citizens to sue to remedy conditions where solid or hazardous waste may present an imminent and substantial endangerment to health or the environment provides a method of coping with risks that were not covered under the RCRA hazardous waste regulatory program. Though, as of yet, no nanowastes have been regulated as hazardous waste, this authority seems the most likely mechanism for dealing with risks associated with nanowastes under the existing regulations.

Additionally, this report concludes that the basic elements required for Superfund cleanup authorities to apply are broad enough in theory to cover nanomaterials. The key threshold issue is whether any nanomaterials now constitute, or will constitute, hazardous substances under the Superfund statute, which highlights the importance of how EPA assesses and designates nanomaterials not only under CERCLA but also under other statutes that it administers as well. Furthermore, even if nanomaterials are not hazardous substances, the statute provides broad authority to EPA to address releases of pollutants and contaminants that present an imminent and substantial danger. In theory, this authority could be used to address nanomaterials; however, EPA would be limited to performing the cleanup itself and could not recover its cleanup costs from responsible parties. Although some of the statutory liability exemptions include a quantity-based element that may not translate well to nanomaterial cleanups, these exceptions also contain a toxicity component that in particular cases may suffice to address concerns about quantity-based exemptions. The cleanup standards and processes set out in the statute are broad enough to apply to cleanups of nanomaterials. If, however, they are to apply effectively to nanomaterial cleanups, EPA will need to review the implementing regulations, policies, and guidance to determine whether amendments are needed to address the unique properties of nanomaterials. Finally, the release-reporting requirements in the statute could apply to releases of reportable quantities of nanomaterials, provided the nanomaterials released constitute hazardous substances under the law. The default reportable quantity of one pound, however, may limit the application of the reporting requirements to nanomaterials in cases in which EPA has not established specific reportable quantities.

Given the pace of regulatory action with respect to nanotechnologies, CERCLA may once again prove important in its role of addressing problems that other statutes have failed to address. In addition, because CERCLA imposes far-reaching liability for cleaning up sites contaminated by hazardous substances, the statute creates substantial private incentives for careful handling of hazardous substances through private monitoring and enforcement. Whether this deterrent function of the statute is or should be operating at this relatively early stage in the development of nanotechnologies is a question that warrants further consideration.

Accordingly, in theory, RCRA and CERCLA are broad enough to be used as vehicles to regulate nanomaterials and nanowastes. In order to use the statutes effectively, EPA will need to make a series of determinations about whether and how to apply these regulatory programs. The task for EPA in making these determinations is particularly challenging, however, as in many cases the data on human health and eco-toxicity that form the basis for such decisions are lacking.

Implications for the Environmental Protection Agency (EPA)

On the basis of the analyses provided in this report, the authors recommend that EPA:

- Further invest in and encourage, using the various means available to it, the development of data on human health and eco-toxicity of nanomaterials and their fate and transport in the environment.
- In conjunction with other federal agencies, conduct outreach and education to the private sector, particularly to small companies and start-ups, about how RCRA and CERCLA could apply to nanomaterials.
- Make decisions about whether and how to apply the statutes to nanomaterials.

Specifically with respect to RCRA:

- Review the four hazardous waste characteristics to determine whether they remain appropriate in light of the possibility that waste nanomaterials may have properties and functions that differ substantially from those of bulk wastes.
- Review the Toxicity Characteristic Leaching Procedure to determine if it accurately predicts the fate and transport of nanowastes disposed on land, and revise it if necessary.
- Consider whether specific nanowastes, or categories of nanowastes, should be listed as hazardous wastes.
- Consider whether specific nanowastes, or categories of nanowastes, should be classified as acute hazardous wastes subject to the 1-kilogram-per-month accumulation rule for generators.
- Conduct research to determine whether existing practices for handling, treating, storing, and disposing of bulk forms of solid wastes are appropriate for nanoscale wastes of the same chemicals.

Specifically with respect to CERCLA:

- Determine whether any current Superfund hazardous substances are produced in nanoform and, if so, assess whether these substances also are hazardous in nanoform and, therefore, covered by the Superfund program.
- Assess whether to use its authority under the Superfund law to evaluate nanomaterials for purposes of determining whether they are hazardous substances.
- Take into account that actions that affect nanomaterials under other statutes it administers could indirectly result in the addition of a nanomaterial to the list of Superfund hazardous substances.

Implications for Firms

The private sector has responsibilities to ensure that nanomaterials and nanowastes are managed safely and in accordance with law. To address these responsibilities, firms should:

- Apply the RCRA hazardous waste rules to nanomaterials, including determining when they become wastes, determining whether those wastes meet the definition of hazardous waste, and managing hazardous wastes as required.
- Recognize that even if nanomaterials do not constitute hazardous wastes under RCRA, at a later date they could be determined by EPA to be hazardous substances under Superfund.
- Dispose of nanomaterials in a manner that accounts for the possibility that they could later be strictly and jointly and severally liable to the government or liable to private parties, if those nanomaterials subsequently are released, or there is a substantial threat of their release, from a facility into the environment.
- Recognize that as a result of CERCLA, RCRA, and other environmental statutes, the environmental due diligence that accompanies many commercial transactions and securities offerings could examine their handling and disposal of nanomaterials.
- Join with universities and government in promoting and conducting research into human health and eco-toxicity of nanomaterials, their fate and transport in the environment, and appropriate methods of handling, treating, storing, and disposing of waste nanomaterials.

Implications for Investors and Insurers

The lack of knowledge about the human health and environmental effects of nanomaterials and the virtual absence of regulatory review at this juncture raises special concerns for insurance companies, investors, and banks. Therefore, these stakeholders should:

- Take into account the potential for CERCLA and RCRA liability arising from releases or disposal of waste nanomaterials and products in drafting new insurance policies, interpreting existing policies, and planning for future potential liabilities.
- Take into account the potential environmental risks and liabilities posed by releases or disposal of waste nanomaterials and products in making lending and investment decisions.

Introduction

Nanotechnology deals with the ability to observe, manufacture, and manipulate materials that have novel properties, on a scale generally between 1 and 100 nanometers. A nanometer is one billionth of a meter, which means that nanomaterials are built on the scale of molecules or even atoms, and on a scale that is just a fraction the size of most living cells. At this scale, materials are affected by quantum effects and other physical and chemical properties in ways that are not significant at larger scales. A carbon nanotube, for example, can be about 1 nanometer wide, or about half the width of DNA.[1] The electrical, magnetic, and mechanical properties of a material can be affected by changes made at the nanoscale.[2] The National Nanotechnology Initiative (NNI) explains that "the physical, chemical, and biological properties of materials [at the nano scale] differ in fundamental and valuable ways from the properties of individual atoms and molecules or bulk matter," which is what makes nanomaterials of such great interest and value.[3] *Nanotechnology* is therefore a very broad term that encompasses many technologies in vastly different fields.

Nanotechnologies, and particularly nanomaterials, are rapidly finding their way into products in the marketplace. Estimates vary, but the worldwide market in products that incorporate nanotechnologies is expected to be in the trillions of dollars in less than 10 years, and possibly much sooner.[4] Nanomaterials are currently in use in consumer products such as sunscreens, cosmetics, tennis rackets and balls, bicycles, stain-free clothing, computer processors and hard drives, catalytic converters, paints, and ink.[5] The Project on Emerging Nanotechnologies at the Woodrow Wilson International Center for Scholars (Wilson Center) has catalogued more than 500 manufacturer self-identified consumer products that use nanotechnologies.[6] Nanotechnologies also have shown significant promise for contributing to improvements in energy-efficient

1. National Nanotechnology Initiative (hereinafter *NNI*), <http://www.nano.gov/html/facts/The_scale_of_things.html> (last visited Feb. 8, 2007).
2. The Royal Society and The Royal Academy of Engineering, *Nanoscience and Nanotechnologies: Opportunities and Uncertainties* (2004), available at <http://www.nanotec.org.uk/finalReport.htm> (last visited Oct. 18, 2006)
3. NNI, <http://www.nano.gov/html/facts/whatIsNano.html> (last visited Feb. 8, 2007).
4. Media Advisory, Nanotechnology: How Well Do We Understand the Environmental and Safety Implications (September 20, 2006) (on file with House Committee on Science).
5. NNI, <http://www.nano.gov/html/facts/appsprod.html> (last visited Feb. 8, 2007); Woodrow Wilson International Center for Scholars Project on Emerging Nanotechnologies, a Nanotechnology Consumer Products Inventory, *available at* <http://www.nanotechproject.org/inventories> (last visited Oct. 17, 2006) (hereinafter *Inventory*).
6. *Id.*
7. John Balbus, Richard Dennison, Karen Florini, & Scott Walsh, *Getting Nanotechnology Right the First Time*, Issues in Science and Technology, 65, 70 (Summer 2005) (hereinafter *Getting Nanotechnology Right*); Nanotechnology Workgroup, Science Policy Council, U.S. Envtl. Prot. Agency, Nanotechnology White Paper at 1, 4 (February 2007), *available at* <http://www.epa.gov/osa/pdfs/nanotech/epa-nanotechnology-whitepaper-0207.pdf> (last visited Mar. 12, 2007) (hereinafter *EPA White Paper*).
8. Ernie Hood, *Nanotechnology: Looking as We Leap*, 112 Envtl. Health Persp. A741, A744 (2004); *EPA White Paper*, *supra* note 7, at 17.

products, environmental remediation, water treatment, and monitoring.[7] For example, field tests of iron nanoparticles have shown them to be highly effective at neutralizing polychlorinated biphenyls, DDT, and dioxin.[8]

Relatively little is known about the effects of nanomaterials on human health or the environment.[9] In fact, the characteristics that make nanomaterials of such interest to materials scientists and others, namely, that their physical, chemical, and biological properties are fundamentally different from those of individual atoms or bulk materials, also make it difficult to predict their effects on human health or the environment based on prior knowledge of the materials in their bulk forms.[10] Thus, new research is needed into the human health and environmental effects of these materials, but such research is at a nascent stage and lags behind research aimed at the development of applications and products.[11] Moreover, there are many types of nanomaterials, with widely varying characteristics, which will need to be investigated for their effects on human health and the environment.

Some nanotechnologies use materials that are known to be toxic in some forms, but their effects in the new technology may be uncertain. For example, quantum dots, or nanocrystals or nanodots, are nanoscale semiconductors whose properties can be adjusted due to their small size. To date, most quantum dots have used heavy metals such as cadmium, selenium, and lead, which are toxic. A review of research into the effects of quantum dots on human health concluded that quantum dots vary substantially and that their toxicity depends both on the varying characteristics of the materials and on environmental conditions. "Importantly, the vastness and novelty of the nanotechnology frontier leave many areas unexplored, or underexplored, such as the potential adverse human health effects resulting from exposure to novel nanomaterials. . . . Although they offer potentially invaluable societal benefits such as drug targeting and in vivo biomedical imaging, [quantum dots] may also pose risks to human health and the environment under certain conditions."[12]

Why Address Nanotechnology End-of-Life Issues?

Several recent reports examine possible governance approaches for nanotechnologies and highlight uncertainties with respect to regulation of the environmental, health, and safety implications of nanotechnology. In *Securing the Promise of Nanotechnology: Is U.S. Environmental Law Up To the Job?*, the Environmental Law Institute (ELI) reported on a dialogue that it co-hosted with the Project on Emerging Nanotechnologies.[13]

9. *See, e.g.,. EPA White Paper supra* note 7, at 32–61 (summarizing research); *but see Getting Nanotechnology Right*, *supra* note 7, at 66 (listing a variety of risks associated with nanomaterials).

10. *Id.* at 33; *see also* Andrew D. Maynard et al., Safe Handling of Nanotechnology, Nature (November 15, 2006) *available at* <http://www.nature.com/news/2006/061113/pf/444267a_pf.html > (last visited March 15, 2007).

11. Project on Emerging Nanotechnologies, <http://www.nanotechproject.org/index.php?id=29> (last visited Oct. 18, 2006); *Getting Nanotechnology Right*, *supra* note 7, at 66-69.

12 Ron Hardman, *A Toxicologic Review of Quantum Dots: Toxicity Depends on Physicochemical and Environmental Factors* 114 Envtl. Health Persp. 165, 165 (2006).

13. Securing the Promise of Nanotechnology: Is U.S. Environmental Law Up To the Job? (ELI 2005) (hereinafter *Securing the Promise*).

14. J. Clarence Davies, *Managing the Effects of Nanotechnology* (Woodrow Wilson International Center for Scholars 2006).

The dialogue explored the extent to which existing laws regulate nanotechnology products, processes, and wastes. Similarly, the Wilson Center report *Managing the Effects of Nanotechnology*[14] describes the possibilities for regulating nanotechnology under current environmental, health, and safety laws. Both reports recognize that there is no law that deals specifically with nanotechnology and that there are significant issues concerning the adequacy of existing laws to deal with nanotechnology. A recent article co-authored by one of the authors of this report argues that a careful analysis of all potentially applicable statutes is essential before reasoned decisions can be made about the need for new legislation or whether existing rules may suffice.[15]

The ELI and Wilson Center reports emphasize the use of the Toxic Substances Control Act (TSCA) as a potential vehicle for regulating nanotechnologies, as it is a product-based, chemical-focused statute that at least initially appears to be the best suited of the existing laws for purposes of addressing the environmental, health, and safety risks that nanotechnologies may pose. To the extent the focus has turned to new laws and governance approaches, most efforts, including those of the U.S. Environmental Protection Agency (EPA) in its recent White Paper,[16] emphasize preventing pollution that may be associated with nanotechnologies. At the same time, however, the ELI dialogue participants, the Project on Emerging Nanotechnologies, the Royal Society and the Royal Academy of Engineering, Environmental Defense, and others have highlighted the importance of taking a full life-cycle approach in developing an effective governance structure for nanotechnologies that would include, for example, basic research and development, manufacturing, and product use and disposal.[17] To date, relatively little attention has been paid to the environmental, health, and safety issues associated with end-of-life or disposal of nanoproducts or nanowastes. Nevertheless, the Royal Academy recognized in its 2004 study that the risk of release of nanomaterials would be highest during disposal, destruction, or recycling.[18]

This report focuses on two federal statutes that are intended to deal with the environmental consequences of materials when they reach the end of their useful lives. The Resource Conservation and Recovery Act (RCRA)[19] was designed to regulate the handling, reuse, recycling, storage, treatment, and disposal of solid wastes, including hazardous wastes. When it became evident that pre-RCRA disposal practices had resulted in significant contamination of land, Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)—commonly

15. Linda K. Breggin & Leslie Carothers, *Governing Uncertainty: The Nanotechnology Environmental, Health, and Safety Challenge*, 31 Columbia J.E.L 285, at 287-88 (2006).

16. *EPA White Paper, supra* note 7, at 18.

17. *Securing the Promise, supra* note 13, at 22-26; *Managing the Effects of Nanotechnology, supra* note 14, at 18-20; *Nanoscience and Nanotechnologies: Opportunities and Uncertainties, supra* note 2, at 85; *Getting Nanotechnology Right, supra* note 7, at 65; Terry Medley & Scott Walsh, Environmental Defense – DuPont Nano Risk Framework, draft (February 26, 2007) *available at* http://www.environmentaldefense.org/documents/5989_Nano%20Risk%20Framework-final%20draft-26feb07-pdf.pdf (last visited Mar. 12, 2007).

18. *Nanoscience and Nanotechnologies: Opportunities and Uncertainties, supra* note 2, at 74.

19. 42 U.S.C. §§6901-6992k (1996).

20. 42 U.S.C. §§9601-9675 (1996).

referred to as Superfund[20]—to clean up sites contaminated with hazardous substances.

Resource Conservation and Recovery Act (RCRA)

Most of the focus on RCRA has been on the part of the statute that deals with hazardous wastes, sometimes referred to as Subtitle C.[21] This focus began with Congress, which created two very different regulatory programs for solid wastes and for hazardous wastes. Because of the heightened concern over hazardous wastes, Congress mandated a strict system of tracking and controlling the handling and transportation of hazardous wastes and set minimum national standards for treatment, storage, and disposal of hazardous wastes. For solid wastes, on the other hand, Congress established criteria and guidelines for states to follow in establishing programs for managing their solid wastes. The solid waste program was designed to be implemented by the states with relatively little federal involvement after the criteria and guidelines had been established.

The hazardous waste program follows a different model. It is one of the federal statutes that establishes requirements that apply nationwide and then allows states to assume responsibility for implementing the hazardous waste program in lieu of the federal program if the state demonstrates that its program is equivalent to the federal program. Only Alaska and Iowa have not sought and received authorization from EPA to implement at least the base RCRA program.[22] An authorized state is allowed to impose standards that are more stringent than those required under the federal law, although relatively few states have availed themselves of this opportunity. This report assumes the minimum federal requirements apply and does not attempt to cover states that may have more stringent requirements.

Subtitle C of RCRA is an ambitious attempt to identify, track, and ensure the safe treatment and disposal of all hazardous wastes. This is accomplished by requiring generators of hazardous waste to identify such wastes and to keep detailed records of all hazardous wastes from the time they are determined to be hazardous until they reach a final treatment or disposal facility. Because of this scheme, RCRA is often described as a "cradle-to-grave" regulatory scheme for hazardous waste. It covers generators and transporters of hazardous waste as well as owners and operators of treatment, storage, or disposal facilities. The cradle-to-grave description is in many ways, however, a misnomer. The "cradle" merely starts at the point at which a substance is determined to be a "waste," even though that substance may have had a long history as a potentially toxic or hazardous substance in use as a raw material, intermediary, or even as a final product in the industrial stream. Nor is it really accurate to say there is a "grave" for hazardous wastes since many such wastes retain their hazardous characteristics after disposal. Hazardous wastes may remain of concern even after disposal because no currently used method of disposal can guarantee that they will remain isolated from the environment forever. Some methods of treatment, such as chemical conversion to non-toxic substances

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21. 42 U.S.C. §§6921-6939e (1996).
22. US EPA, *StATS Data as of March 31, 2005*, <http://www.epa.gov/epaoswer/hazwaste/state/stats/maps/base.pdf> (last visited Nov. 28, 2006).

or complete destruction, are the only truly permanent solutions.

The hazardous waste program has succeeded in its basic goal of improving the practices for handling, treating, and disposing of hazardous wastes. Although it is difficult to measure events avoided, it seems likely that the hazardous waste rules prevented the creation of new Superfund sites. The hazardous waste program has also been credited for having much lower transaction costs than the Superfund program.[23]

RCRA also has its critics. The hazardous waste program has been criticized for being one of the most complex and difficult-to-follow regulatory programs, not just among environmental regulatory programs but among all regulatory programs. It has been criticized for preventing actions that would have clear environmental benefits, such as one company using the hazardous waste of another company as a raw material.[24] RCRA regulations are frequently ridiculed for their length and contrariness. For example, "[o]ne of the ways that a product can be 'discarded' is by being 'recycled.' The term 'recycled' in turn includes both 'speculative accumulation' and 'use constituting disposal.'"[25] The hazardous waste regulations are characterized by numerous exceptions to the basic rules, which often themselves have exceptions or limitations. Although many of these complexities were determined to be necessary to avoid abuses of the rules or to prevent specific practices considered to be harmful, they undeniably make compliance with the rules difficult.

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

CERCLA was enacted in 1980 in response to highly publicized cases in which hazardous waste disposal sites were improperly managed and hazardous substances were spilled, causing contamination that put people at risk of disease or injury. The Act gives the federal government authority to respond to releases of hazardous substances into the environment. The statute also authorizes the federal government to sue persons who are responsible for the release to compel them to perform the cleanup. In addition, the federal government, or a state or tribe, may clean up the release and then recover the cost of the cleanup from the responsible party. EPA operates an extensive cleanup program that focuses on responsible party cleanups as the first option, with government-funded cleanups as a backup. This is commonly referred to as the "Superfund program" after the fund established by the statute to pay for government-led cleanups.

The statute has a broad and inclusive definition of those it holds responsible for contaminated sites, including generators of the hazardous substances, owners or operators of the facility or land, past owners or operators of the facility if they owned or operated it at the time of disposal, and transporters of hazardous substances if the transporter chose the disposal site. Such responsible parties are held liable without regard to fault, when the acts occurred, or who else may have been responsible as well (strict, retroactive, and

23. David B. Kopel, Linda L. Rockwood & Kimberly A. Tempel, *RCRA Demystified: The Professional's Guide to Hazardous Waste Law* (ELI 1996).

24. Elliott Laws, *Fundamental Change in Our Basic Laws*, Environmental Forum, July/Aug. 2004, at 10.

25. Kopel et al. *supra* note 23, at 4.

joint and several liability), but they may seek contributions under certain circumstances from other responsible parties.

Unlike the approach it took with RCRA, Congress did not authorize states to take over implementation of the Superfund program from EPA. In 1986 amendments to CERCLA, Congress directed EPA to involve states in the Superfund program in a substantial and meaningful way, which has led to states being allowed to take the lead in investigating sites within their boundaries, in recommending sites for the National Priorities List, or NPL (the list of sites EPA considers the highest priority for cleanup), and in cleaning up sites on the NPL if they so desire. Fewer than 1,300 sites are listed on the NPL, but states have discovered many more sites that have lesser levels of contamination than necessary to qualify for the NPL. States generally have enacted their own laws governing cleanup of contaminated sites within their boundaries and are cleaning up, or overseeing cleanups by those responsible, at a far larger number of sites than are on the NPL.[26]

Statutes Not Covered

Many federal environmental laws address end-of-life issues to some extent, but are not specifically covered in this report. These include the Clean Air Act, Clean Water Act, Toxic Substances Control Act, Emergency Planning and Community Right-to-Know Act, and Hazardous Materials Transportation Act. This report focuses on RCRA and CERCLA because these two statutes explicitly seek to prevent and to mitigate harm to human health and the environment from hazardous materials at the end of their useful lives. This report does not cover state laws that implement RCRA or that exceed its minimum requirements, nor does it cover state laws that authorize states to clean up sites contaminated by hazardous substances. It is important to recognize, however, that, in addition to the federal laws, these state laws could be used to address end-of-life issues with respect to nanomaterials.

26. *An Analysis of State Superfund Programs 50-State Study 2001 Update* (ELI 2002).

Case Study Scenarios: CNT Inc. and Q-Dot

The following two hypothetical scenarios will be used to explore the issues relating to the application of RCRA and CERCLA to nanomaterials. The hypothetical scenarios are not based on any specific situations, but rather attempt to link theoretical discussion to situations that are within the realm of possibility in order to illustrate how the statutes would work in practice.

CNT Inc.

CNT Inc. was incorporated in 2004 to produce carbon nanotubes (CNTs) for use in various products, such as polymers. CNTs are cylinders made primarily of carbon that are between 1 and 10 nanometers in diameter. The company's founders are scientists who had conducted research on CNTs for several years. Other than an attorney retained to help set up the corporation and to assist with corporate tax and similar issues, the management has no legal or regulatory expertise or knowledge. The company operates out of a modestly sized, stand-alone building that it rents in an area zoned for light industry. For the past year it has been producing CNTs for use in various products. It has steadily increased its production to the point that it is now producing about 80 kilograms (kg) each month. Unfortunately, as much as 25 percent of its production fails to meet product specifications and is unable to be sold. The material looks like soot. Because CNT Inc. expects to eventually be able to reprocess this off-specification CNT material into usable product, it collects the material in plastic containers with lids that snap on and stores it in an otherwise unused corner of its facility.

A few years pass and CNT Inc. continues to be moderately successful, gradually increasing and improving its production, but continuing to reject a percentage of the CNTs as not meeting specifications. At some point management decides that it needs the corner where the off-specification material has been stored and so directs its maintenance staff to move the containers outside, behind the building. Over time, some of the containers have been knocked over or otherwise have had their contents spilled onto the soil.

CNT Inc. is then sold to a larger company that moves the operations to a different facility. The property at which CNT initially operated stands vacant for a few years until an unrelated firm expresses interest in the property. The prospective buyer conducts an environmental assessment of the property and discovers that the CNTs have become mixed with the soils and can be detected in the groundwater at the property.

Q-Dot

A subsidiary of a Fortune 500 corporation, Q-Dot has a full environmental, health, and safety staff, including attorneys that have experience with hazardous waste and hazardous substance laws. Q-Dot produces nanodots, which include metallic ions such as cadmium and selenium that give the materials useful properties such as luminescence. Q-Dot's production process, like that of other nanotechnology companies, is not yet as efficient as Q-Dot would like it to be. One result is the production of a substantial amount of nanodots that do not meet its product specifications. Although its environmental, health, and safety staff think that at least some of the nanodots would be considered hazardous waste under RCRA, Q-Dot never generates more than 100 kg/month of sub-standard nanodots. The company has established a regular schedule for shipping the nanodots to an in-state landfill that has a state permit to receive municipal solid waste and non-hazardous industrial waste.

After many years, groundwater monitoring at the landfill reveals that leachate from the landfill has contaminated the groundwater. The site is investigated by the state and corrective action is required. The corrective action is unsuccessful, and the state recommends the site for inclusion on the National Priorities List. Site records show that Q-Dot sent waste to the landfill for several years, and preliminary investigation reveals the presence of nanodots in the landfill and in the groundwater.

RCRA and the Regulation of Nanotechnology

The Resource Conservation and Recovery Act (RCRA)[27] was designed to deal with waste or end-of-life issues, specifically for solid and hazardous wastes. The statute has three major programs: solid waste, hazardous waste, and underground-storage tanks. Each program is subject to a separate set of regulations. This report does not cover the underground-storage tank program because it does not appear likely that the nanotechnology industry will be using underground storage tanks as a method of storing significant quantities of nanomaterials, although this could change.

A few specific types of wastes are excluded from regulation under RCRA. Wastes regulated under the Atomic Energy Act of 1954 are not subject to RCRA.[28] The Atomic Energy Act (AEA) regulates source material, such as uranium and thorium; special nuclear material, which is defined as plutonium and enriched uranium; and by-product material, which is defined as any radioactive material, except special nuclear material, yielded or made radioactive in the process of producing or using special nuclear material, and uranium or thorium mill tailings.[29] Wastes that are both radioactive (subject to regulation under the AEA) and hazardous are called mixed wastes and regulated under both RCRA and the AEA. Medical waste is not covered as a distinct category of waste, but is covered if it meets the definitions of solid waste and hazardous waste discussed below. In 1988, Congress passed the Medical Waste Tracking Act, under which EPA established a pilot program in Connecticut, New Jersey, New York, Puerto Rico, and Rhode Island, but the program expired after two years and has not been renewed. Wastes regulated under the Clean Water Act or the Safe Drinking Water Act are excluded from regulation under RCRA as well.[30]

Solid Waste

The key issue in applying RCRA to nanotechnologies is whether the substance in question is a solid waste and, if so, whether it is a hazardous waste. This is important because all the RCRA rules depend on whether a substance is a solid waste. In addition to being key to the applicability of the solid waste rules,[31] a substance can be classified as a hazardous waste only if it is first determined to be a solid waste.[32] Though a seemingly simple concept, the determination of whether something is a solid waste is the most complex issue under RCRA and the implementing regulations. The statute defines solid waste to include "solid, liquid, semisolid, or contained gaseous material."[33]

27. A similar statutory analysis was conducted by the American Bar Association's Section on Environment Energy and Resources (SEER). Although this and the SEER paper cover the same issues, the papers were developed independently. American Bar Association SEER, *RCRA Regulation of Wastes from the Production, Use, and Disposal of Nanomaterials,* 2006 A.B.A. Sec. Envtl, Energy, Resources *available at* <http://www.abanet.org/environ/nanotech/pdf/RCRA.pdf> (last visited Nov. 8, 2006).

28. 42 U.S.C. §6905(a) (1996).

29. 42 U.S.C. §2014 (1996).

30. 42 U.S.C. §6905(a) (1996).

31. For a description of the solid waste program, see the Appendix.

32. 42 U.S.C. §6903(5) (1996).

33. 42 U.S.C. §6903(27) (1996).

Thus, only gases that are freely released into the atmosphere are not at least potentially solid wastes. Although Congress did not define waste, possibly because it was assumed to be a well-understood term, the definition of solid waste provides some guidance in referring to "garbage, refuse...and other discarded material."[34]

In its hazardous waste regulations EPA defines solid waste as any *discarded* material that is not specifically excluded from the definition. The regulation then defines discarded material as something that is *abandoned*, *recycled*, or *inherently waste-like*.[35] Material is abandoned if it is *disposed of*, *burned* or *incinerated,* or *accumulated* or *treated* before or instead of being disposed of, burned, or incinerated.[36] In this context, EPA defines recycled material as *spent materials*, *sludges, by-products*, *commercial chemical products,* and *scrap metal*.[37] These materials are solid wastes if they are *used in a manner constituting disposal*, *burned for energy recovery*, *reclaimed*, or *accumulated speculatively*, with a few exceptions. The exceptions include *sludges and by-products that exhibit a characteristic of hazardous waste* (see discussion below) and commercial chemical products, all of which are not considered solid wastes and thus are unregulated when they are reclaimed.[38] Material is considered *used in a manner constituting disposal* if it is applied to or placed on the land or used to produce products that are applied to or placed on the land, but pesticides or other commercial chemical products that are normally applied to land are not solid wastes.[39] Also, commercial chemical products that are fuels are not considered solid wastes.[40] The term *accumulated speculatively* applies to all the listed materials except listed commercial chemical products. It applies to such materials when they are accumulated before being recycled, but does not apply if the material is recyclable and a feasible method of recycling exists and the person accumulating it recycles or transfers to another site for recycling at least 75 percent of the material in a calendar year.[41] Finally, a material is *inherently waste-like* if it is one of several types of hazardous wastes listed by EPA in the regulations.[42]

Exclusions

The statute specifically excludes from the definition of solid waste any solid or dissolved material in domestic sewage, irrigation return flows, and industrial discharges that are point sources under the Clean Water Act, and special nuclear or by-product material as defined by the AEA. In its regulations implementing the statute EPA has excluded 22 types of materials from the definition of solid waste.[43] If a material is so excluded, it is not regulated under RCRA, regardless of whether it might meet the standards for being a hazardous waste. Most of the exclusions would not apply to nanomaterials since the exclusions relate to specific industrial processes such as

34. 42 U.S.C. §6903(27) (1996).
35. 40 C.F.R. §261.2(a)(2) (2007).
36. 40 C.F.R. §261.2(b) (2007).
37. 40 C.F.R. §261.2(c) (2007).
38. 40 C.F.R. §261.2(c) Table 1 (2007).
39. 40 C.F.R. §261.2(c)(2)(ii) (2007).
40. 40 C.F.R. §261.2(c)(1) (2007).
41. 40 C.F.R. §261.2(c) (2007).
42. 40 C.F.R. §261.2(d) (2007).
43. 40 C.F.R. §261.4(a) (2007).

hazardous materials generated and recycled within the petroleum refining industry,[44] or to specific wastes such as cathode ray tubes.[45] These exclusions include:

- **Wastes that pass through a sewer system.** One exclusion that could apply to the nanotechnology industry is for waste that passes through a sewer system and is treated by a publicly owned treatment works (POTW).[46] Thus, if CNT Inc. (see first hypothetical example above) had disposed of its off-specification carbon nanotubes by discharging them along with its sanitary wastes into a sewer system that delivered the waste to a POTW, the waste would not be considered hazardous waste. This analysis does not attempt to consider whether rules under the Clean Water Act or other laws might impose additional requirements on such a discharge. In fact, in December 2006, EPA announced that it would regulate under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)[47] a washing machine that releases silver ions in order to kill bacteria on clothing. EPA determined that the washing machine must be registered as a pesticide because it is "a product that incorporates a substance (silver) that is released into the laundry for the purpose of killing microbial pests."[48]
- **Point sources.** Some in the nanotechnology industry are also likely to be covered by the exclusion for industrial wastewater discharges that are point source discharges subject to regulation under the National Pollutant Discharge Elimination System (NPDES) of the Clean Water Act.[49] The exclusion does not apply to industrial wastewater that is collected, stored, or treated before discharge, nor does it apply to sludge that results from the industrial wastewater treatment. For example, if Q-Dot company (see second hypothetical example above) had an industrial wastewater treatment facility with a discharge permit and the substandard nanodots were part of the industrial wastewater stream, that process would not be subject to regulation under RCRA. But if the company stored or treated the nanodots before they entered the wastewater treatment process, the RCRA rules regulating storage and treatment of hazardous waste would apply. Similarly, RCRA rules could apply if the wastewater treatment process produced sludge that included nanodots. The company would then need to determine whether the nanodots in the sludge met the definition of hazardous waste.
- **Closed-tank recycling.** A third exclusion that might apply to nanomaterials concerns materials that are reclaimed and returned to the original process through a closed-tank system where the materials are not stored for more than 12 months and are not burned, used to produce a fuel, or used to produce a

44. 40 C.F.R. §261.4(a)(12) (2007).
45. 40 C.F.R. §261.4(a)(22) (2007).
46. 40 C.F.R. §261.4(a)(1)(ii) (2007).
47 7 U.S.C. §§ 136-136y (1996).
48. U.S. Environmental Protection Agency (hereinafter *US EPA*), *Regulatory Status Update: Ion Generating Washing Machines*, <http://www.epa.gov/oppad001/ion.htm> (last visited Nov. 8, 2006).
49. 40 C.F.R. §261.4(a)(2) (2007).
50. 40 C.F.R. §261.4(a)(8).

CNT Inc. and Q-Dot: Will Companies Know What Constitutes a Waste?

The hypothetical examples help demonstrate how the regulations can be applied to nanomaterials. The examples are also intended to highlight the issues that need to be considered by the nanotechnology industry in determining whether RCRA applies and, if so, which regulations apply. The CNT Inc. example illustrates the basic question of whether nanomaterials are solid wastes. That question depends first on whether the material is "discarded," which is defined in part as abandoning the material. In the first year, CNT Inc. does not appear to have abandoned or disposed of the off-specification CNT material in the subjective sense. It did accumulate the material and set it aside, which could bring it under the definition of solid waste. Even though the company appears to have intended to save the material for later re-introduction into the production process to regenerate it as usable product, it did not regenerate 75 percent of the material in a calendar year, which would make it a solid waste under the regulations. The state environmental agency or EPA is likely to reach this conclusion, particularly if looking back in light of subsequent events. Several years later, when management decided to move the containers of substandard CNTs outside the building it seems clear that the company had abandoned the material. Moving the material out of the production area, in conjunction with the passage of time and apparent failure to ever re-introduce the material into the production process, could be an indication that CNT Inc. is discarding the material since it is at best being accumulated before or instead of disposal. This would mean it is solid waste. The regulatory significance of such a determination will be explored below.

The Q-Dot hypothetical does not raise a question of whether the substandard nanodots are a solid waste since the company treats them as a solid waste and ships them to an off-site disposal facility. If the company did not manage them as a waste but stored them, as CNT Inc. did, then the same questions might arise as to whether it had discarded the nanodots by abandoning or accumulating them prior to disposing of them.

product that is used in a manner constituting disposal.[50] Though not applicable to either hypothetical example presented in the case studies above, this exclusion could apply if a nanomaterial production process collected any wastes in a closed tank and returned them to the production process.

An additional set of exclusions applies to materials that are within the definition of solid waste but excluded from being considered hazardous wastes. EPA regulations exclude 18 types of solid wastes from the hazardous waste requirements. Some of these are specific to particular facilities while many others (agricultural waste; mining overburden; fossil fuel combustion waste; oil, gas, and geothermal waste; mining and mineral processing waste; cement kiln dust; arsenic-treated wood; petroleum-contaminated media from underground-storage tanks; recycled chlorofluorocarbons; certain used oil filters; used oil distillation bottoms used to produce asphalt; and leachate or gas condensate from landfills) are unlikely to apply to nanomaterials.

The hazardous waste exclusion most likely to apply to wastes that contain nanomaterials is household waste.[51] This exclusion is likely to apply to many nanomaterials in consumer products that consumers dispose of in their household trash. Households include multiple-dwelling residences, hotels and motels, campgrounds, bunkhouses, day-use recreational areas, and similar facilities. Facilities that manage or dispose of household solid waste are covered by the solid waste program, which sets minimum standards for such facilities (see Appendix). Another

51. 40 C.F.R. §261.4(b)(1) (2007).

hazardous waste exclusion that might apply to some nanomaterials covers trivalent chromium waste from wastewater treatment sludge from the production of titanium oxide pigment using chromium ores by the chloride process.

Hazardous Waste

The statutory definition of hazardous waste is relatively straightforward. Hazardous wastes are solid wastes that because of "quantity, concentration, or physical, chemical, or infectious characteristics may (A) cause, or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness; or (B) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed."[52] This definition indicates that Congress was concerned with wastes that cause death or serious illness or that pose a threat to health or the environment when improperly managed.

EPA implemented the statutory definition through regulations that are simple in outline, but extremely detailed. The point of departure in determining whether something is a hazardous waste is that it is a solid waste as defined above. The regulations require a several-step process for determining whether a solid waste is a hazardous waste.

First, if a waste is included on one of several lists of substances or constituents provided in the regulations, it is a hazardous waste. These lists include hazardous wastes from more than 100 specific sources, 39 non-specific sources, and hundreds of discarded commercial chemical products, off-specification species, and other types of wastes.[53] The lists have letter designations (F, K, P, and U) that allow for shorthand reference for those who deal with the regulations on a regular basis. A review of the lists revealed no instance where a waste is listed as a hazardous waste because of its nanoscale size, and there is no indication that EPA is considering listing any nanowastes.

Second, EPA considers a waste hazardous if it has one or more of four characteristics: ignitability, corrosivity, reactivity, or toxicity.[54] Before establishing these characteristics, EPA found that wastes with these characteristics met the statutory definition of hazardous waste.[55] Each of these characteristics is further defined, often with reference to approved test methods. *Ignitability* is defined by specific tests, but generally includes materials that have a flash point of less than 60°C, are spontaneously combustible, or can create fires under certain conditions, such as friction.[56] *Corrosivity* includes strong acids and bases (pH less than or equal to 2 or greater than or equal to 12.5) that corrode metal containers.[57] *Reactivity* refers to wastes that are not stable under normal conditions and that may explode, release toxic fumes when heated, compressed, or mixed with water.[58] *Toxicity* refers to substances that are

52. 42 U.S.C. §6903(5) (1993).
53. 40 C.F.R. §§ 261.31-.33 (2007).
54. 40 C.F.R. §§ 261.20-.24 (2007).
55. 40 C.F.R. § 261.10 (2007).
56. 40 C.F.R. § 261.21(a) (2007); *see also* US EPA, *What is a Hazardous Waste*, <http://www.epa.gov/epaoswer/osw/hazwaste.htm> (last visited Oct. 19, 2006).
57. 40 C.F.R. § 261.22(a) (2007); *see also What is a Hazardous Waste*, *supra note* 56.
58. 40 C.F.R. § 261.23(a) (2007); *see also What is a Hazardous Waste*, *supra note* 56.

harmful or fatal if swallowed or absorbed, but the toxicity regulation requires a test of leaching capability and then the extract must be compared to a list of toxic contaminants and concentration limits.[59] Substances such as arsenic, benzene, cadmium, lead, mercury, selenium, and silver are included in the list.[60] The test of leaching capability, known as the Toxicity Characteristic Leaching Procedure (TCLP), is intended to identify wastes that will leach harmful concentrations of toxic substances after they are disposed in a landfill.[61] Because nanomaterials often do not behave in the same way as bulk materials do, the leaching test may not accurately predict the fate and transport of nanowastes disposed in a landfill. For such nanomaterials, size and properties are likely to be more significant than concentration, which means the TCLP is unlikely to be an adequate test of their fate and transport in the environment.

RCRA provides that the regulations listing particular hazardous wastes and identifying the characteristics of hazardous wastes "shall be revised from time to time...as may be appropriate."[62] The advent of nanowastes with their unique properties may be an appropriate time for EPA to consider revising the identifying characteristics of hazardous waste, particularly the toxicity characteristic and its test, as well as to list particular wastes as hazardous.

EPA has issued regulations providing that a solid waste that is mixed with a listed hazardous waste is a hazardous waste, but this general rule has exceptions, with exceptions to those exceptions.[63] A solid waste that is mixed with a characteristic waste is a hazardous waste if it has the characteristic.[64]

Third, the generator of a solid waste is responsible for determining whether the waste is a hazardous waste. The regulation suggests that the generator first check the exclusions to determine if the solid waste in question is excluded from being a hazardous waste.[65] Thus, a company that manufactures nanomaterials is responsible for making this determination. For characteristic hazardous wastes, the generator must also identify each characteristic that applies and any underlying hazardous constituents (listed in the Universal Treatment Standard Table, see Land Disposal Ban below) in order to determine which land disposal treatment or prohibition rules apply.[66] The regulations allow generators to petition EPA to exclude a waste they generate at a particular facility from the specifically listed hazardous wastes.[67] A number of facilities have been successful with such petitions, and these exceptions are noted in the rules.

A generator of nanowastes must engage in the same analysis as any other generator to determine whether its wastes are hazardous, as illustrated to the hypothetical case study that follows.

Fourth, a solid waste is considered a hazardous waste as soon as it is generated if it is a listed hazardous waste, as soon as a listed hazardous waste is mixed with it, or as soon as it takes on one of the

59. 40 C.F.R. § 261.24(a) (2007).
60. 40 C.F.R. § 261.24 (Table 1) (2007).
61. *What is a Hazardous Waste*, *supra* note 56.
62. 42 U.S.C. §6921(b)(1) (1996).
63. 40 C.F.R. §261.3(a)(2)(iv) (2007).
64. 40 C.F.R. §261.3(b)(3) (2007).
65. 40 C.F.R. §262.11 (2007).
66. 40 C.F.R. §§262.11(c), 268.7, 268.9, and 268.2(i) (2007).
67. 40 C.F.R. § 260.22 (2007).

CNT Inc. and Q-Dot: Is the Nanowaste Hazardous?

First, carbon nanotubes are not named on any of the specific lists of hazardous wastes. Likewise carbon, the element of which they are a structural form, is not listed as a hazardous waste. CNT Inc. would be obligated to determine if its CNT waste met any of the tests for the four characteristics of hazardous waste. It is possible that CNTs might meet the definition of ignitable waste, but based on current knowledge it appears unlikely that they would meet the definitions of the other characteristic wastes. Thus, the off-specification carbon nanotubes produced by CNT Inc. do not appear to be hazardous wastes.

Q-Dot's environmental staff may be correct in thinking that the off-specification nanodots would be considered hazardous waste. Like carbon nanotubes, waste nanodots do not appear to be included in any of the lists of hazardous wastes. In fact, no nanowaste appears to be included in any of the hazardous waste lists. In applying the RCRA regulations to its wastes Q-Dot would be required to determine whether the waste met any of the definitions of characteristic wastes. The TCLP test may apply to nanodots because cadmium and selenium are among the toxic contaminants listed under the toxicity characteristic. If the leachate that results from the leaching test contained cadmium or selenium above their listed concentrations, then the nanodots would be hazardous waste when Q-Dot discarded them.

four characteristics. [68] A hazardous waste remains such for the duration of its existence.[69] There are only a few specified and limited instances when a hazardous waste can be considered to no longer be a hazardous waste. The most generally applicable of these is a characteristic waste that no longer has the characteristic.[70] Nevertheless, if a waste exhibited a characteristic at the time it was generated, it may be required to meet the concentration-based treatment standards for any hazardous constituents before land disposal.[71]

Regulatory Treatment of Hazardous Waste

A fundamental underlying policy premise of RCRA is that the risk associated with hazardous waste is proportional to mass. This premise is significant in applying RCRA to nanomaterials because risks associated with them may be unrelated to mass, and because, at least in the short term, manufacturers of nanomaterials may not generate large quantities of solid waste from their operations. However, even small quantity generators may be affected under some conditions. Congress authorized EPA to issue special rules for generators who generate 100 kilograms or less of hazardous waste per month. They are referred to as conditionally exempt small quantity generators (CESQG) and they are generally exempted from the hazardous waste regulations, except that they must comply with the requirement to determine if their waste is hazardous.[72] There is an exception to the 100-kilogram cutoff for certain hazardous wastes designated as acute hazardous wastes, which have a limit of one

68. 40 C.F.R. § 261.3(b)(1)-(3) (2007).
69. 40 C.F.R. § 261.3(c)(1) (2007).
70. 40 C.F.R. § 261.3(d)(1) (2007).
71. 40 C.F.R. §§ 261.3(d)(1) & 268.40 (2007).
72. 40 C.F.R. §§261.5(b) and 262.11 (2007).

kilogram per month above which the full regulations apply.[73] If a CESQG accumulates more than 1,000 kilograms of hazardous waste (or more than one kilogram of acute hazardous waste) on-site, the generator's hazardous wastes become subject to the regulations applicable to small quantity generators.[74] A CESQG may treat or dispose of its hazardous waste at an on-site facility, or ensure that the waste is delivered to an off-site treatment, storage, or disposal facility (TSDF), that is permitted under the hazardous waste rules, is authorized by a state to handle municipal or non-municipal solid waste and is subject to certain rules of the federal solid waste program, or beneficially uses, reuses, or legitimately recycles or reclaims its waste.[75]

Congress also required EPA to issue special rules for generators who generate more than 100 kilograms but less than 1,000 kilograms of hazardous waste in a month.[76] These generators are referred to as small quantity generators (SQG). EPA has generally exempted small quantity generators from most of the detailed regulations applicable to generators of larger quantities of hazardous waste.[77] Among the rules that do apply to SQGs are some of the record-keeping and manifest requirements.[78] Small quantity generators also are subject to a simplified waste minimization requirement.

Generators of hazardous waste are required to undertake a series of actions intended to ensure that all hazardous wastes are accounted for, handled, and managed appropriately throughout their existence, including during transport, until the time they are treated or disposed, including:

- **Waste-minimization programs.** Congress declared a national policy to minimize the generation of hazardous waste by "encouraging process substitution, materials recovery, properly conducted recycling and reuse, and treatment."[79] Despite this general statement, the statute has only two provisions relating to minimizing waste and neither requires specific action to further the policy. Generators that ship hazardous waste off-site are required to sign a certificate that they have a program to reduce the volume and toxicity of the hazardous waste they generate, or, if they are a SQG, that they have made a good faith effort to minimize their generation of hazardous waste.[80] Generators must also submit a biennial report that describes their efforts to reduce the volume and toxicity of hazardous wastes generated and the changes in volume and toxicity achieved during the past year in comparison to prior years.[81]
- **Label, manifest, and transportation requirements**. Generators must comply with packaging, labeling, marking, and placarding rules issued by the Department of Transportation (DOT) under the Hazardous Materials Transportation Act[82]

73. 40 C.F.R. §261.5(e)(1) (2007).
74. 40 C.F.R. §261.5(g)(2) (2007).
75. 40 C.F.R. §261.5(g)(3) (2007).
76. 42 U.S.C. §6921(d) (2006).
77. 40 C.F.R. §§261.44 (2007).
78. 40 C.F.R. §§261.20 & .44 (2007).
79. 42 U.S.C. §6902(a)(6) (1996).
80. 40 C.F.R. §262.27 (2007).
81. 40 C.F.R. §262.41(6) & (7) (2007).

before transporting hazardous wastes.[83] Generators are responsible for choosing an appropriate facility to which to send their hazardous wastes for treatment, storage, or disposal. A manifest system was established to ensure that hazardous wastes are tracked throughout their transportation and that they are received at the designated facility. Generators are required to prepare a manifest whenever they transport, or offer for transport by a transporter, hazardous waste off-site.[84] The generator must specify one facility, and may designate an alternate facility, to receive the hazardous waste, and the transporter is required to deliver the hazardous waste to the specified facility or the alternate if an emergency prevents delivery to the primary facility.[85] Failing these two options, the generator must designate another facility or the transporter must return the hazardous waste to the generator.[86] The generator, each transporter, and the owner or operator of the designated facility must each retain a copy of the manifest, and a final copy must be returned to the generator.[87]

- **Temporary storage.** Generators are allowed to accumulate hazardous waste on-site for 90 days without obtaining a permit as a hazardous waste storage facility.[88] SQGs are allowed to accumulate their hazardous wastes for longer times, as long as they do not accumulate more than 6,000 kilograms of hazardous

Q-Dot: Application to Nanowastes

As long as it generates no more than 100 kg/month of hazardous waste (assuming that the TCLP would result in the nanodots meeting the toxicity characteristic), Q-Dot will be a CESQG, which means that it is not required to meet the full set of generator regulations and has extended time periods for others, such as accumulation. Because the company is a CESQG, its practice of sending its hazardous waste to a state-permitted or licensed solid waste landfill rather than a facility with a permit to treat, store, or dispose of hazardous waste would be permissible under the regulations. Whether it is appropriate to treat nanowastes the same as bulk materials is an open question. If the toxicity or environmental availability of nanowastes differs substantially from that of wastes with larger particle sizes, then it might be appropriate to consider whether they should be classified as acute hazardous wastes or to develop new standards for treatment, storage, and disposal of such wastes.

If Q-Dot increased its production without substantially improving its quality, it might produce more than 100 kg/month of hazardous waste, which would make it a small quantity generator subject to more of the regulations applicable to generators. It is possible that in the near term many manufacturers of nanomaterials could fit this category. The regulations have quite specific requirements for using proper containers for hazardous waste, labeling those containers, storing them in appropriate places, and keeping records, all of which necessitate trained and knowledgeable staff. Nanomaterial manufacturers that have not had experience with hazardous wastes should be made aware of these requirements.

82. 49 U.S.C. §§5101–5127 (2005).
83. 40 C.F.R. §262.31 (2007).
84. 40 C.F.R. §262.20 (2007).
85. 40 C.F.R. §262.20(b)-(d) (2007).
86. 40 C.F.R. §262.20(d) (2007).
87. 40 C.F.R. §262.22 &.23 (2007).
88. 40 C.F.R. §262.34(a) & (b) (2007).

waste.[89] Each category of generator must comply with some standards for storing hazardous waste, with SQGs subject to fewer requirements than large-quantity generators. The hazardous waste must be placed in containers, tanks, or container buildings, or on drip pads, and the generator must comply with specific standards applicable to the type of storage used.[90] The generator must also maintain records of the procedures for ensuring that wastes are removed before the 90-day period expires and document each removal of waste; label containers and tanks as hazardous waste; and mark the date that accumulation began on each container.[91] SQGs must comply with only the latter two record-keeping requirements.[92]

Transportation, Treatment, Storage, and Disposal

Transporters of hazardous waste must comply with EPA regulations governing transportation of hazardous waste as well as with more-extensive DOT regulations governing transportation of hazardous materials.[93] A transporter must obtain an EPA identification number before transporting any hazardous waste.[94] As a general matter, transporters are not involved in decisions about the destinations for hazardous waste; the generator must specify an appropriate facility. Transporters must comply with the manifest system, including not accepting hazardous waste from a generator without a signed manifest.[95] Transporters must deliver the entire quantity of hazardous waste to the designated, or alternate, facility, unless the facility rejects the load or part of the load, in which case the rejection of a partial load triggers a requirement for a new manifest in addition to the original.[96] If hazardous waste is discharged during transportation, the transporter must clean up the discharge as directed by federal, state, or local officials so that there is no hazard to human health or the environment.[97]

Determining whether a material is a solid waste and then whether the solid waste is a hazardous waste may be the most conceptually difficult task for regulated entities under RCRA, but the regulations governing treatment, storage, and disposal of hazardous waste are vital to the success of the hazardous waste program. The statute requires EPA to issue regulations governing owners and operators of TSDFs, which must cover record keeping; manifesting; operating methods, techniques, and practices; location, design, and construction of the facilities; contingency planning; permitting and compliance with permits; maintenance; training for personnel; and financial responsibility.[98]

EPA promulgated rules in 1980 establishing minimum national standards for these aspects of hazardous waste management and has updated them since then.[99] Among

89. 40 C.F.R. §262.34(d) (2007).
90. 40 C.F.R. §262.34(a)(1)& .34(d) (2007).
91. 40 C.F.R. §262.34(a)(1)-(3) (2007).
92. 40 C.F.R. §262.34(d)(4) (2007).
93. 40 C.F.R. §263.10(a)(Note) (2007).
94. 40 C.F.R. §263.11 (2007).
95. 40 C.F.R. §263.20 (2007).
96. 40 C.F.R. §263.21 (2007).
97. 40 C.F.R. §263.31 (2007).
98. 42 U.S.C. §§6924(a)(1)-(6) (1996).
99. 40 C.F.R. §264.1(a) (2007).

other standards, EPA has established design standards for each type of hazardous waste management facility, such as tank systems, surface impoundments, landfills, and incinerators.[100] Congress also mandated, and EPA has issued regulations implementing, a ban on the land disposal of liquid and many other types of hazardous wastes unless they are first treated.

Before treating, storing, or disposing of hazardous waste, an owner or operator of a TSDF must conduct, or obtain from the generator, a sufficiently detailed chemical and physical analysis of a representative sample of the hazardous waste to enable the owner or operator to manage the hazardous waste appropriately.[101] This requirement likely will be critically important to operators of TSDFs in managing hazardous nanowastes, but the lack of knowledge about the characteristics of such wastes suggests that it may be difficult to meet this standard.

There is little evidence that nanowastes are currently being managed as hazardous wastes. If a generator determined that its nanowastes were hazardous under the regulations, it would be required to select a TSDF that could properly manage those wastes. This would raise an issue of what would be the appropriate methods of treating, storing, and disposing of nanowastes, which can be answered only if additional research is conducted into the fate and transport of nanomaterials in the environment.

Imminent and Substantial Endangerment to Health and the Environment

RCRA authorizes EPA to sue any person who has contributed to or is contributing to handling, storage, treatment, transportation, or disposal of solid or hazardous waste that may present an imminent and substantial endangerment to health or the environment.[102] If EPA proposes to settle any claim of imminent and substantial endangerment, it is required to provide notice, opportunity for a public meeting in the affected area, and opportunity to comment on the proposed settlement before it is made final.[103]

Citizens are authorized to sue, subject to certain limitations, any person, including any government agency, under the same imminent and substantial endangerment standard.[104] Citizens are also authorized to sue any person alleged to be in violation of any requirement under the statute, including requirements in a permit, regulation, condition, or order.[105] The limitations on such citizen suits include a requirement to provide written notice of any violation or endangerment to EPA, the state in which it occurred, and any alleged violator or person alleged to have contributed to or to be contributing to the endangerment; the suit may not be filed until 60 days after the notice is provided (90 days for imminent and substantial endangerment suits); and no suit is permitted if EPA or the state has begun and is diligently prosecuting a civil or criminal suit to require compliance or is taking any

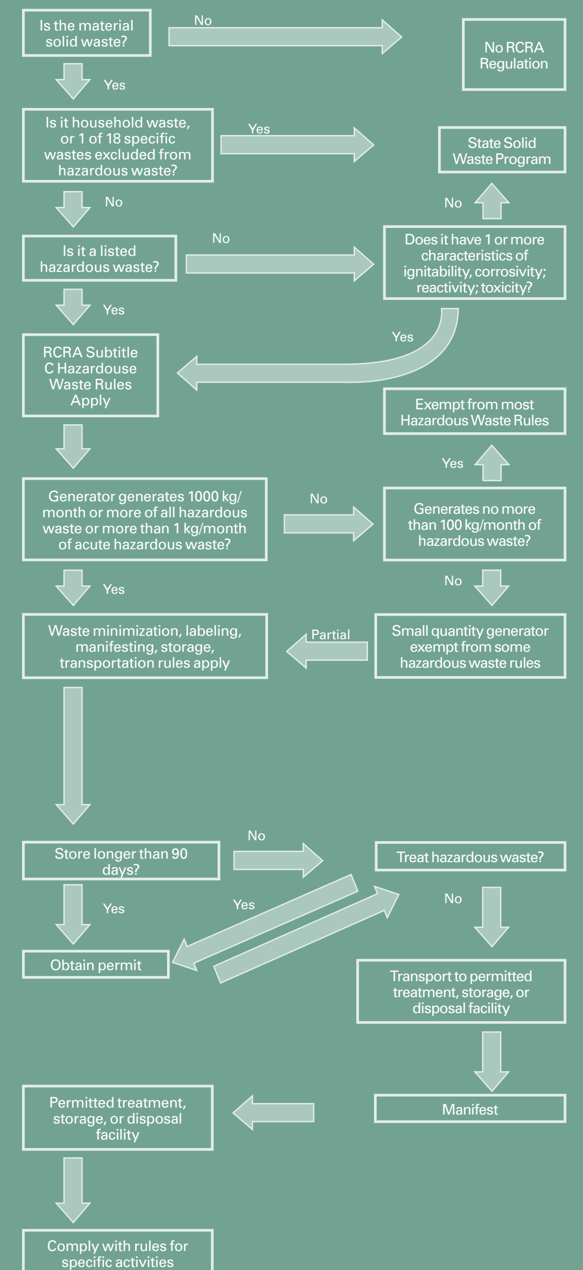
100. 42 U.S.C. §6924 (c) - (e) (1996) and 40 C.F.R. Part 268 (2007). *See e.g.* 40 C.F.R. 264 Subpart J – Tank Systems, Subpart K – Surface Impoundments, Subpart N – Landfills, and Subpart O - Incinerators. (2007).
101. 40 C.F.R. §264.13(a) (2007).
102. 42 U.S.C. §6973(a) (1996).
103. 42 U.S.C. §6973(d) (1996).
104. 42 U.S.C. §6972(a)(1)(B) (1996).
105. 42 U.S.C. §6972(a)(1)(A) (1996).

of several actions to halt or abate the acts or conditions contributing to the endangerment.[106] Actions that will preclude a citizen suit include that EPA is diligently pursuing a suit to require cleanup by the responsible party under either the federal imminent and substantial endangerment authority of RCRA or the comparable section of CERCLA, that EPA is undertaking a removal action under CERCLA, has started a remedial investigation and feasibility study (RI/FS) in preparation for a remedial action under CERCLA, or that the responsible party is conducting a RI/FS or a remedial action under a court order or administrative order under CERCLA.[107] A citizen suit is also barred if a state is diligently pursuing cleanup of the site under its similar RCRA or CERCLA authorities.[108]

The provisions allowing EPA and citizens to abate acts or conditions that may present an imminent and substantial endangerment apply to any solid waste, not just to hazardous wastes. Courts may grant injunctive relief in such cases by ordering defendants to stop taking actions that may be contributing to the risk or to take affirmative action to remove or clean up the wastes. Liability under these provisions is strict, joint, and several.[109]

EPA also is required to provide notice to affected local governments as soon as it receives information that hazardous waste is present at a site that has presented an imminent and substantial endangerment to health or the environment and to require that such notice be posted at the site.[110]

RCRA Regulation of Hazardous Waste



106. 42 U.S.C. §6972(b) (1996).
107. 42 U.S.C. §6972(b)(2)(B) (1996); for a discussion of the relevant provisions of CERCLA *see text accompanying* notes 115 – 128 *infra*.
108. 42 U.S.C. §6972(b)(2)(C) (1996).
109. United States v. Aceto Agric. Chem. Corp., 872 F.2d 1373 (3d Cir. 1984).
110. 42 U.S.C. §6973(c) (1996).

These provisions are among the most powerful tools, particularly for citizens, for dealing with unforeseen problems that arise in the management of solid and hazardous wastes. In the context of the first hypothetical example, if EPA determined that the CNTs in the soils and groundwater at the facility that CNT Inc. formerly operated constituted an imminent and substantial endangerment to health or the environment, then the agency could sue CNT Inc. to clean up the site. As a backup to the federal authority, a citizen could sue CNT Inc. after giving 90 days' notice to EPA, the state, and CNT Inc. if none of them took action to clean up the site. The same authorities could be used to require the landfill operator in the Q-Dot hypothetical case to clean up the contamination from the landfill.

Conclusion

In summary, a review of RCRA indicates the following:

- In principle, RCRA and its implementing regulations cover nanowastes.
- The focus of the statute and regulations on mass as a determinant of regulatory coverage is not necessarily appropriate for nanowastes.
- Disposal of most consumer products containing nanomaterials is likely to be exempt from the hazardous waste regulations as household waste.
- Some nanowastes likely will be excluded from the definition of solid waste and thus from regulation under RCRA because they are disposed into a sewer system and treated by a publicly owned treatment works or disposed of through a point source regulated under the federal Clean Water Act permit system, yet the adequacy of those systems to treat nanowastes is not clear.
- EPA has the authority to add a nanowaste or category of nanowastes to the list of hazardous wastes, but that seems unlikely at this time.
- The toxicity characteristic component of the regulatory definition of hazardous waste seems most likely to apply to nanowastes, but the toxicity characteristic leaching procedure may not be appropriate for nanowastes.
- Some waste nanomaterials likely will be classified as hazardous wastes under the existing rules, either as listed hazardous wastes or under the toxicity characteristic.
- It is possible that some nanowastes will have fundamentally different characteristics than they have in bulk form. This may result in some nanowastes being considered hazardous wastes that do not present the same risks as in their bulk form. Conversely, other nanowastes that should be considered hazardous may not be classified as hazardous because their bulk forms do not meet any of the tests.
- Research is needed to determine whether existing practices for handling, treating, storing, and disposing of bulk forms of solid wastes are appropriate for nanoscale wastes of the same chemicals.
- Many generators of nanowastes may have insufficient information to provide to owners or operators of treatment, storage, and disposal facilities to enable them to manage such wastes appropriately.
- The authority for EPA and citizens to sue to remedy conditions where solid or hazardous waste may present an imminent and substantial endangerment

to health or the environment provides a method of coping with risks that were not covered under the RCRA hazardous waste regulatory program. This authority seems the most likely mechanism for dealing with risks associated with nanowastes under the existing regulations.

CERCLA and the Regulation of Nanotechnology

Overview of the Superfund Statute

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly called the Superfund law, is the other major federal environmental law that addresses disposal of hazardous substances, which includes hazardous wastes.[111] While the other law, RCRA, focuses on the handling of hazardous waste from generation to disposal, the Superfund law addresses inactive or abandoned hazardous waste sites, many of which were the product of decades of uncontrolled and undocumented methods of hazardous substance disposal. CERCLA also was intended, in part, to create incentives for proper future handling of hazardous substances. The enactment of the Superfund law is commonly attributed to the public outcry that resulted from the national media attention paid to particularly troubling cases of hazardous waste disposal, such as the Love Canal site in New York, where a chemical company buried chemicals on a property that was later used for a school and homes.[112]

CERCLA seeks to achieve its goals of site cleanup and proper hazardous substance management through two principal approaches. First, the law provides EPA with broad authority to clean up, or require private parties to clean up, releases of hazardous substances. EPA also may seek reimbursement from private parties for its cleanup costs. Second, the statute authorizes private parties to sue other private parties under certain circumstances for the cleanup costs they have incurred.[113] CERCLA provisions concerning the first approach authorize EPA to remove, remediate, or take other response measures at a site at which there has been a release, or substantial threat of a release, into the environment of a *hazardous substance*. The response measures also may address contaminated natural resources, if necessary to protect the public health, welfare, or environment.[114] Response action must be consistent with the National Contingency Plan (NCP), the regulations that govern the Superfund program. The statute also authorizes EPA to take response actions when there is a release or substantial threat of release of a *pollutant* or *contaminant* that may present an imminent and substantial danger to public health or welfare.[115]

Superfund takes its name from the revolving fund set up to finance hazardous substance site cleanups. It was initially financed primarily through a tax on

111. CERCLA authorities are not delegable to the states, as are many federal environmental programs such as RCRA. Almost all the states, however, have enacted laws similar to the federal Superfund law that in theory could apply to nanomaterials. Environmental Law Institute, *supra* note 26.

112. Robert V. Percival et al., Environmental Regulation: Law, Science and Policy 366-67 (5th ed., Aspen Publishers 2006); John Pendergrass & Katherine N. Probst, Estimating the Costs of Institutional Controls 6 (Environmental Law Institute & Resources for the Future 2005).

113. As discussed below, the Supreme Court has interpreted the statute to limit the circumstances in which private parties may bring contribution actions. *See* note 158 *infra* and accompanying text.

114. 42 U.S.C. § 9604(a)(1) (2005).

115. 42 U.S.C. § 9604(a)(1) (2005).

chemical feedstock, which expired at the end of 1995. The program is now funded through annual appropriations from general revenues[116] and relies primarily on interest and enforcement receipts.[117]

CERCLA authorizes EPA to conduct two types of cleanups: removal and remedial actions.[118] Removal actions are short-term responses to immediate threats posed by the release or substantial threat of release of a hazardous substance. EPA has completed numerous removal actions since the program started.[119] For example, Superfund's Emergency Response Program, which is part of the Removal Program, was involved in the efforts to reduce immediate threats to human health following Hurricane Katrina. Removal actions, which are typically paid for by EPA, usually are limited to $2 million and the duration of one year.[120]

In contrast, remedial actions are intended to be permanent solutions.[121] The statute provides numerous examples of remedial actions including: perimeter protection using dikes, trenches, or ditches; clean up of released hazardous substances and associated contaminated materials; collection of leachate and runoff; and repair of leaking containers.[122] Of the 1,243 sites on the National Priorities List, which is the list of sites determined to be most in need of remediation, EPA has designated 1,006 sites as "construction complete," meaning that the Agency had determined that physical construction of the remedy is finished and that immediate and long-term threats are under control.[123]

The statute creates liability for a wide range of parties associated with the release of hazardous substances at a Superfund site: *owners and operators*[124] of sites, including current owners or operators and any prior owners or operators during the time of disposal of hazardous substances; *generators* of hazardous substances who arranged for disposal or treatment, or who arranged for transportation for disposal or treatment; and *transporters* of hazardous substances if they selected

116. John Pendergrass, Legal Background to Off-Site Contamination, in When Bad Things Happen to Good Property 213, 218 (Robert A. Simons et al., Environmental Law Institute, 2005).

117. Letter from John B. Stephenson, Director of Natural Resources and Environment, U.S. General Accounting Office, to James M. Jeffords, Committee on Environment and Public Works, U.S. Senate (Feb. 18, 2004), <http://www.gao.gov/new.items/d04475r.pdf> (last visited Dec. 6, 2006).

118. 42 U.S.C. § 9604 (2005).

119. Since 1980, EPA estimates that more than 49 million people have been protected from hazardous substance releases though the emergency response program: 200,000 people provided with a safe supply of drinking water; over 40,000 people moved from the vicinity of dangerous sites and provided temporary housing; and hazardous wastes contained or treated, including over 10 million cubic yards of contaminated soil and debris, 1,569 million gallons of contaminated liquids, 288 million gallons of polluted water. U.S. Environmental Protection Agency, *The EPA Emergency Response and Removal Program* <http://www.epa.gov/superfund/resources/emer_res.htm> (last visited Mar. 1, 2006).

120. 42 U.S.C. § 9604 (c) (2005).

121. The statute defines remedial actions as "actions consistent with permanent remedy taken instead of or in addition to removal actions in the event of a release or threatened release of a hazardous substance into the environment, to prevent or minimize the release of hazardous substances so that they do not migrate to cause substantial danger to present or future public health or welfare or the environment." 42 U.S.C. § 9601(24) (1996).

122. 42 U.S.C. § 9601(24) (1996).

123. Environmental Protection Agency, *Number of NPL Site Actions and Milestones by Fiscal Year* <http://www.epa.gov/superfund/sites/query/queryhtm/npltotal.htm> (last visited Oct. 17, 2006).

124. 42 U.S.C. § 9601(20) (1996).

the site.[125] The law applies not only to private parties but also in many ways to federally owned facilities.[126]

The nature of the liability that is imposed on parties under CERCLA is far-reaching. The liability is strict, joint and several, and retroactive. This means that parties can be held liable for actions taken before the Superfund statute was enacted (retroactive), regardless of fault or negligence (strict), and that such parties can be liable for the entire cleanup, even if they generated, transported, or are otherwise responsible for only a portion of the hazardous substances at the site (joint and several). Furthermore, the defenses to liability under the statute are quite limited and include, for example, when a release of a hazardous substances was caused by an act of war or an act or omission of a third party.[127] The deterrent effects of this liability system and its application to nanomaterials are discussed in detail later.

EPA can use appropriated monies from the Trust Fund to perform emergency removal work as well as remedial work at NPL sites contaminated with hazardous substances. EPA's "enforcement first" policy, however, provides that EPA will first seek to require the parties responsible for the hazardous substances to conduct site cleanups, rather than use Superfund money. Thus, since 1991, responsible parties, rather than the government, have cleaned up the majority of Superfund sites.[128] EPA typically uses appropriated funds when parties liable for contamination cannot be found or are financially unable to pay for the cleanup.[129] In cases in which the government performs the cleanup, CERCLA authorizes in certain circumstances actions to recover response costs from responsible parties, as discussed below.[130]

The second approach taken by CERCLA is to authorize private parties to sue other private parties to recover response costs incurred in cleaning up hazardous substances sites. The statute provides that a person may seek contribution under certain circumstances from another person who is liable or potentially liable under the statute and that a court may allocate response costs among liable parties using equitable factors that the court determines are appropriate.[131]

The Superfund program fills an important niche in the environmental regulatory scheme by providing a means to address hazardous substance contamination that the system has failed to address prospectively through other laws. Given the current pace of regulatory action with respect to nanotechnologies, it is this statutory role that may once again prove important, if it is necessary, based on information and data collected over time, to remediate nanomaterials that have been released into the environment.

More than 25 years after its enactment, however, the Superfund program continues to generate controversy. For example, cleanups under the statute are criticized as too lengthy

125. 42 U.S.C. § 9607(a) (2002).

126. 42 U.S.C. § 9620 (1996) (law made applicable to federally–owned facilities in 1996).

127. 42 U.S.C. § 9607(b) (2002).

128. EPA can require responsible parties to remediate sites through a settlement agreement or through an administrative order. 42 U.S.C. § 9606 (1996).

129. Katherine N. Probst et al., Superfund's Future: What Will it Cost, a Report to Congress 33 (Resources for the Future 2001).

130. 42 U.S.C. § 9607 (2002).

131. 42 U.S.C. § 9613(f)(l) (1996).

and costly.[132] Perhaps the principal criticism, however, is the unusually far-reaching liability scheme, which many view as unfair, particularly when combined with the authorization of private cost-recovery actions. In fact, the history of the program is rife with efforts to challenge and amend the statute's liability approach legislatively, judicially, and administratively. These efforts have yielded some legislative and administrative changes to the program over time, but for the most part the basic liability system has remained intact.

Regardless of whether the system is viewed as fair, the combined threats of EPA enforcement and private litigation appear to have a substantial deterrent effect. Specifically, the statute may provide strong incentives to reduce and carefully manage wastes.[133] The influence on private business transactions is notable. For example, in 2001 the roughly $400 million EPA enforcement budget was less than the more than $500 million spent on Phase I-type private environmental assessments of properties,[134] which are conducted in large part to determine if there are hazardous substances on a site that could lead to Superfund liability. In addition, more than 70% of all corporate acquisition agreements filed with the Securities and Exchange Commission by publicly traded firms include environmental terms,[135] many of which are related to CERCLA liability. Accordingly, the Superfund program appears to create a substantial amount of private incentives for careful handling of hazardous substances through private monitoring and enforcement.

It is this deterrent function of the statute that is perhaps the most interesting when viewed in the context of nanomaterials at this relatively early stage in the development of nanotechnologies. The question of whether the statute is affecting the level of care used or otherwise influencing the handling and disposing of nanomaterials today is discussed more fully below.

Before examining in more detail whether Superfund provides appropriate cleanup authorities and public and private incentives for proper handling of nanomaterials, it is important to note that nanomaterials not only may constitute hazardous substances that are subject to the Superfund law but also may be used increasingly as a means of site remediation under the program. As explained by EPA, the benefits of using nanomaterials for remediation "could include more rapid or cost-effective cleanup of wastes relative to current conventional approaches...[s]uch benefits may derive from the enhanced reactivity, surface area, subsurface transport, and/or sequestration characteristics of nanomaterials."[136] For example, zero-valent iron has

132. Probst, *supra* note 129, at 1-2.

133. Robert V. Percival et al., Environmental Regulation: Law, Science and Policy 367-68 (5th ed., Aspen Publishers 2006); Philip T. Cummings, *Completing the Circle*, Environmental Forum, Nov./ Dec. 1990, at 11; U.S. Department Of Justice Press Release, July 3, 1997, 97-281, "Clean Up Of Missouri Toxic Waste Site Complete Times Beach Superfund Site Last Of Three Toxic Waste Sites To Be Cleaned Up That Spurred Creation Of The Superfund Law;" Testimony of Hon. Carol M. Browner, Administrator, U.S. Environmental Protection Agency, Superfund Reauthorization: Federal Agency Perspectives, June 27, 1995, House of Representatives, Subcommittee on Water Resources And Environment, Committee On Transportation And Infrastructure, Washington, DC.

134. Michael P. Vandenbergh, *The Private Life of Public Law*, 105 Colum. L. Rev. 2029, 2045, 2052, 2056 (2006) (Similar percentages for credit agreements ("almost 70%") and commercial real estate lease agreements ("almost 80%")).

135. *Id.* at 2048-49.

136. *EPA White Paper*, *supra* note 7, at 17-18.

been used successfully to remediate groundwater. Specifically, it is used to construct a permeable reactive barrier to intercept and dechlorinate chlorinated hydrocarbons in groundwater plumes. Studies indicate that nanoscale zero-valent iron also could be used to remediate dense, nonaqueous-phase liquid sources of contaminants within aquifers.[137] In essence, the Superfund program has competing interests, as nanomaterials could be used to improve the effectiveness of cleanups but also may present cleanup challenges.

Could the Superfund Statute Apply to Nanomaterials?

For Superfund authorities to apply to the cleanup of nanomaterials, several threshold conditions must be met.[138] Before proceeding, however, it is critical to note that much of the Superfund program is implemented through regulations, the NCP,[139] and administrative policy and guidance documents. This analysis is limited to the statutory terms. Although the statute governs and constrains these administrative tools, an understanding of how the program applies to nanomaterials cannot be complete without a review and analysis of these detailed and often complex documents, some of which are referenced below.

- **Is there a hazardous substance?** Hazardous substances are defined by reference to substances that are listed pursuant to the Superfund statute or designated under other environmental statutes.[140] For example, the substances designated under other statutes include hazardous substances and toxic pollutants under the Clean Water Act,[141] hazardous air pollutants under the Clean Air Act,[142] hazardous waste under RCRA,[143] and imminently hazardous chemical substances or mixtures under TSCA.[144] More than 800 substances are considered hazardous substances under Superfund

137. *EPA White Paper*, *supra* note 7, at 67; Greg Wilson, *Nanotechnology Applications for Remediation: Cost-Effective and Rapid Technologies; Removal of Contaminants From Soil, Groundwater; and Aqueous Environments* at 24-27 <http://es.epa.gov/ncer/publications/meetings/8-18-04/pdf/greg_wilson.pdf> (last visited Dec. 04, 2006).
138. A similar statutory analysis was conducted by the American Bar Association's SEER. Although this and the SEER paper reach similar conclusions, the papers were developed independently. American Bar Association Section of Environment, Energy, and Resources, *CERCLA Nanotechnology Issues*, 2006 A.B.A. Sec. Envtl, Energy, Resources <http://www.abanet.org/environ/nanotech/pdf/CERCLA.pdf> (last visited 1/31/2007).
139. 42 U.S.C. § 9660 (1996).
140. 41 U.S.C. § 9601(14) (1996)("The term 'hazardous substance' means (A) any substance designated pursuant to section 1321(b)(2)(A) of title 33, (B) any element, compound, solution, or substance designated pursuant to pursuant to section 9602 of [title 42], (C) any hazardous waste having the characteristics identified under or listed pursuant to section 3001 of the Solid Waste Disposal Act…(but not including any waste regulation of which under the Solid Waste Disposal Act…has been suspended by Act of Congress), (D) any toxic pollutant listed under section 112 of the Clean Air Act…, and (F) any imminently hazardous chemical substance or mixture with respect to which the Administrator has take action pursuant to section 2606 of title 15," and includes an exception for petroleum, as follows: "the term does not include petroleum, including crude oil or any fraction thereof which is not otherwise specially listed or designated as a hazardous substance [under the statute]….").
141. Clean Water Act § 311, §307, 33 U.S.C. § 1321 (b)(2)(a) (2005).
142. Clean Air Act § 112, 42 U.S.C. § 7412 (a)(6)(b) (2005).
143. 42 U.S.C. § 6921 (2005).
144. Toxic Substances Control Act § 7, 15 U.S.C. § 2607 (2005).

CNT Inc. and Q-Dot: Are the Materials Hazardous Substances?

To return to the earlier hypothetical case studies, the key questions are whether EPA, or possibly a court interpreting EPA regulations, has determined or will determine that either carbon nanotubes or nanodots are hazardous substances. The nanodots contain a heavy metal, cadmium, which may be considered a hazardous substance under Superfund because of its designation as a characteristic waste under RCRA. The question, which has not been answered yet by EPA, is whether the nanoform is also considered a hazardous substance when used as a component of a nanodot. The carbon nanotubes in our hypothetical probably would not qualify as hazardous substances under CERCLA because they have not been designated specifically under CERCLA or the statutes referenced in CERCLA and are not listed in bulk form. Either substance could be designated as a hazardous substance at a later date, however, and the statute would apply, as discussed below. An area for further study is to examine the standards under the various statutes referenced by the Superfund law to determine the likelihood, based on the standards used under those statutes, that nanomaterials could or will in the future qualify as hazardous. In addition, further research is needed to determine the standards EPA would use to designate a substance as hazardous under Superfund, independent of a designation under another statute.

because of designations made under these statutes.[145] In addition, EPA specifically can designate hazardous substances under the Superfund program that may present substantial danger to public health or welfare or to the environment;[146] however, to date, this authority appears not to have been used.

Thus, the two principal ways by which a nanomaterial could become subject to CERCLA are (1) if EPA, or possibly a court interpreting EPA's regulations, decides that a substance currently subject to the statute includes the substance in its nano form; or (2) if EPA specifically designates a nanomaterial as a hazardous substance under CERCLA or under a statute referenced in CERCLA. EPA's current list of hazardous substances under Superfund does not include any specific nanomaterials,[147] and the programs that implement the laws referenced by Superfund have not specifically listed nanomaterials as hazardous. Further study, however, could identify hazardous substances that are listed under the Superfund law, or the other statutes, in bulk form that are currently produced in nanoform.

In any event, a key question is whether EPA will list any nanomaterials in the future under CERCLA or the other relevant programs. To date, EPA has been virtually silent on this question as it pertains to Superfund. In a somewhat analogous context, however, there has been robust debate among interested parties as to whether nanomaterials constitute "new" chemicals

145. US EPA, *Legal Authorities Defining Hazardous Substances* <http://www.epa.gov/superfund/programs/er/hazsubs/lauths.htm> (last visited Mar. 1, 2006).
146. 42 U.S.C. § 9601 (14) (1980); 42 U.S.C. § 9602 (1996); 40 C.F.R. § 302.4 (2007).
147. 40 C.F.R. Part 302 (2007).

under TSCA.[148] From the perspective of influencing the level of care used in handling nanomaterials today, an indication from EPA that it may consider some nanosubstances hazardous substances for purposes of Superfund—either now or in the future—could have a substantial effect.

- **Is there a pollutant or contaminant?** Although not frequently used, the Superfund statute provides authority for EPA to respond to a release or a substantial threat of a release of any pollutant or contaminant, as opposed to a hazardous substance, that may present an imminent and substantial danger. Pollutants and contaminants are defined broadly and more inclusively than are hazardous substances under the statute.[149] The statute provides authority for EPA itself to perform the cleanup, but does not permit EPA to recover its costs from, or issue cleanup orders to, private parties. It cannot be ruled out that some nanomaterials could qualify, either now or at a later date, as pollutants or contaminants. Thus, this authority could be particularly important in addressing contamination from nanomaterials, as pollutants and contaminants are defined more broadly than are hazardous substances. Use of this authority to address nanomaterials would be at the discretion of EPA and would depend on available funds.

- **Is there a release or substantial threat of a release?** For the Superfund statute to apply to the cleanup of hazardous substances, there must be a release or substantial threat of a release of a hazardous substance. The definition of *release* under the statute is quite broad and includes, but is not limited to, for example, "any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing into the environment (including the abandonment or discarding of barrels, containers, and other closed receptacles containing any hazardous substance or pollutant or contaminant)." There are certain exemptions that include, for example, workplace releases and emissions from engine exhaust of motor vehicles.[15]

It is important to note that, in contrast to the approach taken in many environmental laws, CERCLA for the most part does not set a threshold amount or quantity of hazardous substances that must be present in order for a response action to be taken under the statute. The quantity of a release, however, is a factor under the reporting requirements of the statute that are discussed in more detail later. The quantity of a release also can be a factor in determining cleanup priorities,[151] reaching settlements, and in applying certain limited liability exemptions, as discussed below.

148. American Bar Association SEER, *supra* note 138; American Chemistry Council Nanotechnology Panel, Views of the American Chemistry Council Nanotechnology Panel on the Broad Scope of EPA's Authority Under TSCA to Address Any Potential Risks From Engineered Nanoscale Materials 2 (Mar. 2006)(on file with author) (concluding that "EPA has ample authority to address any potential risk that engineered nanoscale materials may pose.")

149. 42 U.S.C. § 9601(33) (1996).

150. 42 U.S.C. § 9601(22) (1996).

151. US EPA, Environmental Protection Agency, *Preliminary Assessment/Site Inspection* <http://www.epa.gov/superfund/whatissf/sfproces/pasi.htm> (last visited July 6, 2006).

CNT Inc. and Q-Dot: Is There a Release from a Facility into the Environment?

Returning to the hypothetical scenarios, in both cases it appears likely that a "release" for purposes of the Superfund statute has occurred. A release of the carbon nanotubes occurred when the containers were discarded and abandoned and the soot spilled onto the soil. The nanodots were released as well when they were sent to a landfill for disposal and when the nanomaterials later leached into the groundwater. Similarly, the releases were into the "environment," including onto land and into groundwater. In addition, the landfill and the manufacturing site would each constitute a "facility" under the statute.

- **Is it from a facility?** The release of the hazardous substance must occur from or at a "facility," in order for a party to be liable under the statute for performing or paying for the cleanup. The word *facility* is defined broadly in the statute as "any site or area where a hazardous substance has been deposited, stored, disposed of, or placed or otherwise come to be located." The statute also lists examples of "facilities," such as buildings, structures, installations, equipment, pipes or pipelines, wells, pits, landfills, storage containers, and ditches. Consumer products in use and vessels are specifically are excluded from the definition.[152] Accordingly, there are many situations in which nanomaterials could be released from a place that constitutes a "facility" under the statute.
- **Is it in the environment?** Finally, the release of the substance must be into the "environment." The statute provides that surface water, groundwater, drinking water supplies, land, and ambient air all qualify.[153] It is not difficult to identify ways in which releases into the environment could occur.

In summary, it appears that the basic statutory elements could apply in the context of nanomaterials. The pivotal question is whether a particular nanomaterial constitutes a hazardous substance (or pollutant or contaminant) under the law. This highlights the importance of the approach that EPA adopts in the coming years, under several of the statutes it administers, in deciding whether and how to review and treat nanomaterials not only under CERCLA but also under the Clean Air Act, the Clean Water Act, TSCA, and RCRA. Several commentators, however, have questioned EPA's ability as a general matter to address nanomaterials effectively under these statutes, because of both lack of resources and insufficient legal authority.[154]

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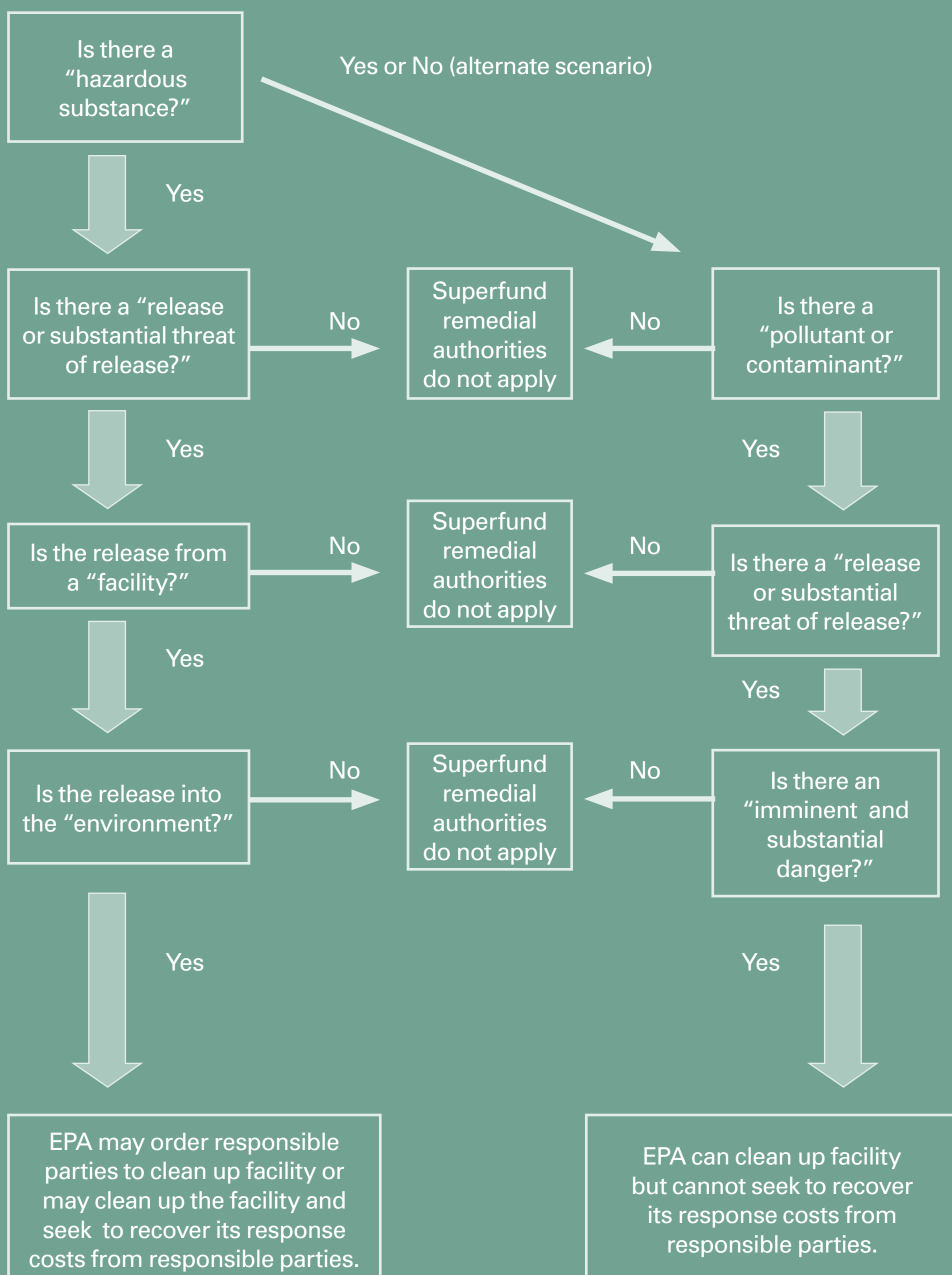
152. 42 U.S.C. § 9601(9) (1996).
153. 42 U.S.C. § 9601 (8) (1996).
154. *Managing the Effects of Nanotechnology*, *supra* note 14; Renewable Resources Foundation, *Environmental Impacts of Emerging Contaminants,* 24,1Renewable Resources Journal, at 21 (Spring 2006)(Ryan M. Colker and Robert D. Day, Eds.); *Compare CERCLA Nanotechnology Issues, supra* note 138 *with* Views of the American Chemistry Council Nanotechnology Panel on the Broad Scope of EPA's Authority Under TSCA to Address Any Potential Risks From Engineered Nanoscale Materials, *supra* note 148.

EPA Remedial Actions Under Superfund



CNT Inc. and Q-Dot: Liability

In our hypothetical case studies, both CNT Inc. and Q-Dot could be responsible parties, provided the nanomaterials that they produce meet the definition of a hazardous substance under the statute. Both could be generators of hazardous substances within the meaning of the statute. CNT Inc. also could be considered a site owner. Furthermore, it is possible that the company that acquires CNT Inc. could be determined to be a responsible party, depending on the nature and extent of the acquiring parent company's activities.

How Would the Liability and Enforcement Authorities Apply to Nanomaterial Cleanups?

The statute's liability scheme bears further discussion because it highlights the broad potential reach of the statute. It is this liability scheme, which has remained intact with limited exceptions, despite numerous judicial challenges and statutory amendments, that could apply years from now to firms, universities, and other organizations that today are disposing of nanomaterials. *Superfund casts a wide liability net.* As discussed earlier, several types of parties can be liable under the statute, including owners and operators, generators, and transporters. The liability generally extends to federally owned properties and, therefore, in theory could cover the federal facilities that today are conducting research on and otherwise handling nanomaterials.[155]

As discussed, the statute imposes strict, joint and several, and retroactive liability, and the defenses to liability under the statute are limited and have been narrowly construed by courts.[156] First, because the liability is "retroactive," a firm can be held liable for actions taken before the Superfund statute was enacted. This aspect of the liability scheme has limited relevance in the nanotechnology context, as the majority of nanowastes have yet to be generated.

Because the liability is "strict," a firm can be held liable, regardless of fault. Thus, even if a company, such as our hypothetical nanodot firm, handled its waste with due care, in a non-negligent manner, and was in compliance with current laws and regulations at the time of disposal (e.g., the nanomaterials do not qualify as a hazardous substance under Superfund at the time of disposal), it still could be required to conduct or to pay for the cleanup of the landfill to which it sent its nanomaterials, if the materials subsequently are determined to be hazardous substances. In this scenario, Superfund would act as it has before to

155. There are currently 157 federal facilities on the NPL. According to the U.S. Department of Energy, the following federal facilities are currently conducting nanotechnology research as part of the Department's contribution to the National Nanotechnology Initiative: Argonne National Laboratory, Lawrence Berkeley National Laboratory, Brookhaven National Laboratory, Sandia National Laboratories and Los Alamos National Laboratory. US EPA, *National Priorities List Active Superfund Sites* <http://oaspub.epa.gov/oerrpage/advquery> (last visited Dec.05, 2006); U.S. Department of Energy, *The Nation's Premier Scientific User Facilities for Interdisciplinary Research at the Nanoscale* <http://www.science.doe.gov/Sub/Newsroom/News_Releases/DOE-SC/2006/nano/index.htm> (last visited Dec. 6, 2006).

156. The defenses include, for example, that the release of a hazardous substances was caused by an act of war or an act or omission of a third party. 42 U.S.C. § 9607 (b) (2002).

catch problems that the rest of the environmental regulatory system failed to address for a variety of reasons, including lack of information.

In addition, liability under the statute, as interpreted by the courts, is "joint and several." This means that unless a firm can prove that the harms at the site are divisible, as is rarely the case, for example, at a landfill, the firm can be held responsible for the entire cleanup, even if it only generated, transported, or arranged for disposal of a portion of the hazardous substances at the site.[157] Firms can sue other firms in certain circumstances[158] to recoup response costs that exceed their fair share, as discussed in more detail below. The objective of imposing joint and several liability, in part, is to shift the burden to responsible parties to seek contributions from other entities that contributed hazardous substances to a site rather than to impose the burden on the government.[159] Thus, the hypothetical nanodot company could be responsible for the entire cleanup of the landfill, even if it contributed only a portion of the hazardous substances at the site. If the company did incur such costs, it may be able to sue other responsible parties, although in addition to the transaction costs, there would be a risk that the firms sued would be insolvent or otherwise judgment-proof.

An important area for further research is the extent to which the prospect of Superfund liability is affecting firms' handling of nanomaterials today. For example, some firms may have environmental management systems[160] that are set up, in part, to protect against Superfund liabilities or more generally to evaluate significant environmental aspects of their activities. As a result, such firms may have specifically considered their potential liability under Superfund and RCRA with respect to nanomaterials.[161]

157. This result would not be typical, however, according to EPA: "Though we have this broad authority, EPA has historically tried to implement the statute fairly, especially through administrative reforms to the program like funding orphan share." US EPA, *Superfund Frequently Asked Questions: Laws, Policy, and Guidance* <http://www.epa.gov/compliance/resources/faqs/cleanup/superfund/laws-faqs.html#2> (last visited Mar. 23, 2006).

158. *Cooper Indust., Inc. v. Aviall Servs., Inc.* 543 U.S. 157, 125 S. Ct. 577 (2004) (clarifies that contributions claims under the statute (Section 113(f)) are permitted only when the party paying for the cleanup had been sued by an authorized government agency or resolved its liability to the government through an administrative or judicial settlement).

159. Pendergrass, *supra* note 116.

160. For a discussion of environmental management systems generally, Feldman, I & Weinfield, D, Environmental Management Systems: Policy, Regulatory and Management Implications of EMS and Related Standards, Chapter in M. Gerrard, Environmental Law (Matthew Bender 2001).

161. *See, e.g.,* Nanophase Certified IS0 140001, <http://www.azonano.com/news.asp?newsID=853> ("Nanophase Technologies Corporation has been certified as having met the international standards of ISO 14001:2004, an Environmental Management Standard. An audit of the Company's Burr Ridge and Romeoville, IL facilities and environmental systems was recently conducted by an ANSI accredited third party auditor, SGS Systems of Rutherford, NJ. As a result of the audit and Nanophase's demonstration of the robustness of its Environmental Management System, ISO 14001certification has been granted."); Hitachi High-technologies Corp., ISO 14001 (international standard for environmental management systems), <http://www.hitachi-science.co.jp/english/about/iso14001.html> (last visited February 15, 2007)("We obtained ISO 14001 certification for our environmental management systems in January 1998. Since April 2004, all subsidiaries under the Nanotechnology Products Business Group of Hitachi High-Technologies Corp have vigorously launched a group-wide environmental improvement program, and acquired ISO certification for total environmental management in November 2004.").

Alternatively, many firms may not be taking steps to ensure that their nanomaterials are handled in a manner that will help ensure against future Superfund liabilities. If the latter is the case, for small and start-up companies in particular, it may be the result of a lack of familiarity and experience with environmental regulatory programs, lack of resources to devote to environmental management, unsophisticated environmental management systems, or poor housekeeping practices.[162]

Both small and large firms, however, are less familiar with nanomaterials than with the bulk chemicals that many of these firms have handled for decades. As a result, nanomaterials may not be effectively integrated into their environmental management programs. Furthermore, because little is known about the toxicity of nanomaterials, firms could conclude that the nanomaterials they are handling are not hazardous substances or, because of the small quantities, are not subject to current regulatory programs. These are all questions that further study could elucidate.

Liability Exemptions

To ensure some level of fairness from the risk of litigation for CERCLA liability, the statute encourages the government to reach expedited, final settlements with so-called *de minimis* parties. *De minimis* parties are defined as: (1) landowners who are past or present owners of property on which a facility is located who did not conduct or permit the handling of any hazardous substances at the facility and who did not contribute to the release of hazardous substances;[163] and (2) waste contributors whose contribution to the hazardous substance release is minimal in volume and toxicity in comparison with the other hazardous substances at that site.[164]

It is certainly plausible that the relative *quantity* of nanomaterials at any particular site could be minimal. As more is learned about nanomaterials, it is possible that the statutory exception should be amended in some manner to take into account nanomaterials. The *de minimis* party protections, however, do not apply if the *toxicity* of the nanomaterials is not minimal compared with that of other hazardous substances at a facility. Whether the toxicity of the nanomaterials at a particular site is determined to be minimal will depend on the facts of each case and on EPA's regulations and policies interpreting the exception.

In addition, the Small Business Liability Relief and Brownfields Revitalization Act of 2002, which amends the Superfund statute,[165] provides a so-called *de micromis* exemption. Transporters and generators that contributed less than 110 gallons or 200 pounds of materials containing hazardous substances to a site are not liable if all or part of the disposal, transport, or treatment occurred before April 1, 2001, provided the materials did not significantly contribute to the cost of the cleanup or restoration of natural resources.[166] In addition, the amendments provide an exemption for small businesses, including tax-exempt non-profits and residential owners and lessees, that contributed only municipal solid waste (MSW) to a site, unless the waste contributed significantly to

162. Breggin & Carothers, *supra* note 15 at 31.
163. 42 U.S.C. § 9622 (g)(1)(B) (1996).
164. 42 U.S.C. § 9622 (g)(1)(A) (1996).
165. 42 U.S.C. § 9607(o) (2002).

the cost of the response action or natural resource damage restoration.[167]

Because most nanomaterials will not have been disposed of prior to April 2001, the *de micromis* exemption is unlikely to apply in the nanomaterial context. Furthermore, the MSW exception, which could apply in the case of the hypothetical nanodot firm, applies only if the contribution is not a significant cost of the response action. Whether a contribution is deemed significant will depend on the facts of a particular case and on EPA's definition of "significant," as it administers the statute.

Natural Resource Damages

The Superfund law imposes liability not only for the costs of removal or remedial actions but also for damages for injury to, destruction of, or loss of natural resources that belong to, are managed by, are held in trust by, appertain to, or otherwise are controlled by a state, the federal government, or Indian tribes that result from the release of a hazardous substance. The liability includes the costs of assessing the injury, destruction, and loss.[168] The definition of "natural resources" is broad and includes land, wildlife, fish biota, air, water, drinking water supplies and more.[169] The statute provides for the designation of federal, state, and tribal "trustees" that may assess damages and bring actions to recover funds from private parties. The funds recovered can be used to restore, replace, or acquire equivalent resources.[170]

The statute's treatment of natural resource damages differs in several ways from its approach to response costs. First, as noted, the statute imposes liability for damages only to natural resources that are owned or held in trust by certain governmental entities. In practice, however, this covers a wide range of natural resources. For example, resources under the trusteeship of the Secretary of the Department of Commerce include, but are not limited to, coastal environments, including salt marshes, tidal flats, estuaries, or other tidal wetlands; endangered marine species; marine mammals; and rivers or tributaries to rivers that support anadromous fish (fish that spend a portion of their lifetime in both fresh and salt water). Examples of resources under the trusteeship of the Secretary of the Department of Interior include certain anadromous fish; certain endangered species; certain marine mammals; and migratory birds.[171] Second, the Trust Fund may not

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166. Prior to enactment of the statutory exemption for *de micromis* parties, EPA issued its Revised Guidance on CERCLA Settlements with *De Micromis* Waste Contributors (June 3, 1996). The policy recommends cutoffs for eligibility at: 0.002 percent (of total volume) or 110 gallons/200 pounds of materials containing hazardous substances, whichever is greater; or 0.2 percent of total volume for contributors that sent only municipal solid waste (MSW). If a *de micromis* party is threatened with litigation by private parties, EPA's policy provides that it will settle with that party for $0 in a settlement agreement that protects such parties from further litigation. Another approach EPA has taken to protect *de micromis* parties is the inclusion of waivers in settlement agreements that provide that the settling parties waive their contribution rights against *de micromis* parties. 1995 Remedial Design/Remedial Action model consent decree, US EPA, *Round 3-14: Revised De Micromis Guidance* <http://www.epa.gov/superfund/programs/reforms/reforms/3-14.htm> (last visited Mar. 1, 2006).

167. 42 U.S.C. § 9607(p) (2002); see also 42 U.S.C. §§ 9601(40) & 9607(r) (2002) (perspective purchaser exemption); 42 U.S.C. § § 9601(35) (innocent landowner exemption).

168. 42 U.S.C. § 9607(a)(4)(C) (2002).

169. 42 U.S.C. § 9601(16) (1996).

170. 42 U.S.C. § 9607(f)(1) (2002), § 9607(f)(2) (2002).

171. US EPA, *Natural Resource Damages, Trust Resources* <http://www.epa.gov/superfund/programs/nrd/trust_r.htm#pagetop> (last visited Mar. 1, 2006).

be used to pay for natural resource damage claims.[172] Third, CERCLA provides federal and state trustees with "the force and effect of a rebuttable presumption" for the determination and assessment of damages to natural resources, if they are performed in accordance with the assessment regulations promulgated under the statute.[173] Accordingly, if trustees perform assessments in accordance with the regulations, the results of assessments will be presumed to be correct.[174] Fourth, the statute does not impose retroactive liability for damages that occurred prior to enactment of the statute in 1980.[175]

For many years after enactment of the statute, the number of natural resource damage claims was limited. The number, however, has increased in recent years.[176] The statute does not specify a method for determining natural resource monetary damages, although it requires trustees to develop standard methods.[177] Because the approach used can have a tremendous effect on the size of the damages, the methods for measuring damages have been a point of much debate, including litigation over the rules initially promulgated by trustees. Over the years, several high-profile cases seeking large claims and involving large settlements in the tens and hundreds of millions of dollars have intensified the controversy.[178]

Similar to the liability provisions that apply to response work at a site, the natural resource damage authorities in theory could apply to damages caused by nanomaterials, if the rest of the statutory requirements are met. Thus, in the Q-Dot hypothetical, if the leachate containing nanomaterials from the landfill contaminated groundwater owned by the state, Q-Dot could be liable for natural resource damages. Likewise, CNT Inc. could be liable if, for example, the soot from the containers migrated to an adjacent wetland owned by the federal government.

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172. Although CERCLA provides authority for the Fund to pay NRD claims, 42 U.S.C. § 9611(a)(3)&(b) (1996), the Superfund Amendments and Reauthorization Act of 1986 and the Internal Revenue Code prohibit Superfund monies from being appropriated to pay such claims, 26 U.S.C. § 9507(c)(1)(A) (1996); US EPA, *Natural Resource Damages Frequently Asked Questions* <http://www.epa.gov/superfund/programs/nrd/faqs.htm> (last visited Mar. 1, 2006).
173. 42 U.S.C. § 9607 (f)(2)(C) (2002).
174. 42 U.S.C. § 9617(f)(2) (1996); Environmental Protection Agency, *Natural Resource Damage Assessment* <http://www.epa.gov/superfund/programs/nrd/primer.htm> (last visited Mar. 1, 2006).
175. 42 U.S.C. § 9607(f)(1) (2002). In addition, as interpreted in the Department of Interior's regulations, a trustee must show by a preponderance of evidence that the hazardous substance release was the sole or substantially contributing cause of injury to natural resources. Thus, as implemented, strict liability is not imposed for natural resource damages, as it is for hazardous substances. U.S. Department of the Interior Natural Resource Damage Assessment Regulations, 43 C.F.R Part 11 (1995) (as amended at 61 Fed. Reg. 20609 (May 7, 1996)); US EPA, *Natural Resource Damages Frequently Asked Questions* <http://www.epa.gov/superfund/programs/nrd/faqs.htm> (last visited Mar. 1, 2006).
176. Environmental Law Institute, *Mitigation of Impacts to Fish and Wildlife Habitats: Estimating Costs and Identifying Opportunities*, Envtl L. Inst. (forthcoming 2007).
177. 42 U.S.C. § 9651(c) (1996).
178. For example, the Montrose Chemical Corp. and other defendants settled a case in October 2000 for disposal of DDT and PCBs on the ocean floor off of California that provided for payments of $43 million for cleanup activities and $30 million in natural resource damages ($73 million total). A partial settlement of $260 million was reached by the Department of Justice and Atlantic Richfield Corp. in November 1998 for contamination from mining activities in the Clark Fork River Basin, Montana. Mark Reisch, *CRS Report: Superfund and Natural Resource Damages* (Jan. 2001) (NCSE Doc. No. 20772). <http://www.ncseonline.org/nle/crsreports/waste/waste-35.pdf> (last visited Oct. 20, 2006).

Enforcement

As discussed earlier, the statute not only enables EPA to take enforcement actions but also enables private parties to conduct cleanups and to sue other private parties to recover costs. Contrary to years of practice and precedent, however, a 2004 Supreme Court case[179] held that a contribution action by a private party to recover cleanup costs is permitted under the statute only if the party paying for the cleanup has been sued by an authorized government agency or has resolved its liability to the government through an administrative or judicial settlement. The decision has been interpreted in varying ways by the lower courts and, therefore, the reach of the decision is somewhat unclear.[180] Nevertheless, the decision is significant because it limits a common practice by which private parties initiated cleanups in the absence of government enforcement actions and then later sought contribution from other responsible parties. Nevertheless, the threat of Superfund liability arises not only from government action but also from private action. As a result, the risk of liability is far greater than it would be if the statute authorized only EPA to take enforcement actions.

The two key types of government enforcement that are authorized by the statute are: (1) issuance of administrative orders that require abatement of actual or potential releases that may create imminent and substantial endangerment to health, welfare, or the environment[181] and (2) cost-recovery actions.[182] In addition, EPA is granted enforcement authorities with respect to entry to facilities, inspection, and sampling.[183] EPA also is provided with settlement authorities.[184] The statute further contains numerous fine and penalty authorities that can be imposed for violations of the statute, administrative orders, and consent decrees.[185] These fine and penalty authorities are general enough that they could apply with respect to parties responsible for nanomaterial cleanups.

Finally, the statute authorizes citizen suits to be brought against any person, including the government, who is in violation of any standard, regulation, condition, requirement, or order that has become effective under the statute. For example, a citizen suit could be brought against a private party for failure to comply with the terms of an administrative cleanup order. The statute also authorizes actions against EPA where there is a failure to perform any act or duty that is not discretionary. Most of the authorities granted to EPA in the statute are discretionary rather than mandatory. In addition, the statute places limits on judicial review of EPA's selection of removal and remedial actions and its issuance of cleanup orders.[186] Analysis of the case law interpreting the citizen suit authority, however, may indicate whether the statute could authorize citizens to require EPA to take some type of action, whether case specific or policy

179. *Cooper Indust., Inc. v. Aviall Servs., Inc,*, 543 U.S. 157 (2004).
180. Larry Schnapf, *Impact of Aviall on Real Estate and Corporate Transactions.* <http:/www.environmental-law.net/article/documents/Aviall.doc> (last visited Dec. 04, 2006).
181. 42 U.S.C. § 9606 (1996).
182. 42 U.S.C. § 9607 (2002).
183. 42 U.S.C. § 9604 (e) (2005).
184. 42 U.S.C. § 9622 (2002).
185. 42 U.S.C. § 9609 (1996), § 9603 (1986), § 9622(l) (2002), § 9604(e)(5)(B) (2005).
186. 42 USC 9613 (h) (1996).

based, with respect to sites contaminated with nanomaterials.

Could the Statutory Cleanup Standards and Processes Apply to Nanomaterials?

Assuming that the statute's liability scheme applies to the cleanup of nanomaterials, this section examines the statute's cleanup standards and procedures to determine whether they could be applied to nanomaterials. As emphasized earlier, much of the cleanup process is set out in the NCP, the regulations that govern the Superfund program, and are beyond the scope of this statutory analysis.[187] Furthermore, an examination of whether the cleanup standards and processes are viable rests in large part on questions of science and technology, including knowledge about the fate, transport, and toxicity of nanomaterials.

Nevertheless, as outlined below, the statutory language that addresses cleanup standards and procedures could apply to nanomaterials, even if regulations and policies may require adjustments.

- **Cleanup Standards and Remedy Selection**.[188] The statute addresses standards for cleanups in several ways. First, it states that there should be a presumption in favor of permanent cleanup remedies, including permanent treatment.[189] The statute does not define a permanent remedy, but it states that land disposal is not a permanent remedy and, therefore, is a disfavored technique. Congress intended this provision to eliminate the problem that wastes from Superfund sites were simply being transported around the country for disposal at other sites where they were contributing to new releases of hazardous substances. Second, the statute generally requires a cleanup to meet any standards from other federal or state statutes that are "legally applicable" or "relevant and appropriate" (often referred to as "ARARs").[190] Thus, if a standard under another federal or state statute by its terms would be legally applicable to a site, then the cleanup must meet that standard. Similarly, if a standard from another federal or state statute, though not legally applicable, would be relevant and appropriate to be applied to the site, then the cleanup must meet that standard as well.

  The statute provides additional criteria to guide the selection of a remedy, but these allow EPA considerable discretion. In deciding what action to take to remedy a site, EPA must consider the long-term uncertainties of land disposal; the goals and requirements of the federal solid and hazardous waste laws; the persistence, toxicity, mobility, and propensity of hazardous substances to bioaccumulate; the short- and long-term potential to cause human health problems; long-term maintenance costs; the potential for failure of the remedial action and the resulting costs for future remedial action; and the potential threat to human health and the environment due to excavation, transportation, and redisposal or containment.[191] After considering these factors, EPA must choose a remedy that protects human health and

187. 42 U.S.C. § 9605 (2002) .

188. Portions of this subsection are adapted from *Protecting Public Health at Superfund Sites: Can Institutional Controls Meet the Challenge?* Environmental Law Institute (1999).

189. 42 U.S.C. § 9621(b)(1) (1996).

190. 42 U.S.C. § 9621(d) (1996).

the environment, that is cost-effective, and that uses permanent[192] solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable.[193] If the remedy will leave hazardous substances, pollutants, or contaminants at the site, EPA must review the remedial action every five years to ensure that it continues to protect human health and the environment.[194]

The terms of the statute appear general enough to apply to nanomaterials. It may be years, however, until the data are available to enable the effective application of the statutory cleanup standards and remedy selection criteria to nanomaterial cleanups. For example, today there is much that needs to be learned about the persistence, mobility, and propensity of nanomaterials to bioaccumulate and about their short- and long-term potential to cause human health problems. In addition, although at least conceptually the statutory approach can be applied to nanomaterial cleanups, a review of the NCP will be needed to determine whether the regulations should be amended before they could be applied effectively to the cleanup of nanomaterials.

- **Cleanup Procedures.** For each step in the process outlined below, the statutory language that applies, if any, appears general enough to account adequately for nanomaterials. The regulations would need to be reviewed, however, to determine whether and how they could be applied at sites with releases, or substantial threats of releases, of nanomaterials.

Site Discovery. Sites can be identified by a variety of parties and through various means, including: notifications by those that handled hazardous materials; investigations by state, tribal or local governments; inventory efforts by government agencies; review of state and federal records; formal citizen petitions; and informal community observation and notification.[195] Because of the nature of nanomaterials, many of the ways in which sites are identified today, such as citizen reports of barrels that are leaking chemicals into a stream, may not be effective. In addition, federal and state investigators may not have the technology and tools to detect nanomaterials during inspections, as discussed in the Introduction.

Preliminary Assessment/Site Inspection (PA/SI). The PA and SI evaluate the potential for a release of hazardous substances from a site. The PA is an assessment of information about a site and its surrounding area. The PA is designed to distinguish, based on readily available and limited data, among those sites that pose little or no threat to human health and the environment and those sites that may pose a threat and require further investigation. The PA also identifies sites that may require emergency-response actions. If the PA recommends

191. 42 U.S.C. § 9621(b)(1) (1996).
192. 40 C.F.R. 300.430(e)&(f) (2007).
193. 42 U.S.C. § 9621(b)(1) (1996).
194. 42 U.S.C. § 9621(c) (1996); 40 C.F.R. 300.430 (f)(4)(ii) (2007).
195. US EPA, *Superfund Clean Up Process* <http://www.epa.gov/superfund/action/process/sfproces.htm> (last visited Jul. 6, 2006).

further investigation, a SI is performed.[196] The SI provides the data needed for Hazard Ranking System[197] (HRS) scoring and documentation. Samples are typically collected to determine the types of hazardous substances at the site, the substances being released into the environment, and whether the wastes have reached nearby populations and environments.[198]

HRS Scoring. If further assessment is needed, EPA uses the HRS to screen sites for placement on the NPL. Numerical values are given to factors that relate to risk, based on conditions at the site. These factors are divided into three categories: the likelihood that a site has released or has the potential to release hazardous substances into the environment; characteristics of the waste, such as toxicity and quantity; and people or sensitive environments affected by a release. Four pathways can be scored: "groundwater migration (drinking water); surface water migration (drinking water, human food chain, sensitive environments); soil exposure (resident population, nearby population, sensitive environments); and air migration (population, sensitive environments)."[199]

NPL Listing Process. On the basis of the HRS score, a site may be identified as appropriate for possible long-term cleanup and placed on the NPL.[200] The statute provides that the criteria for establishing priorities must be based on relative risk or danger to public health, welfare, or the environment, taking into account to the maximum extent possible factors such as the population at risk, the hazard potential of the hazardous substances at the facility, the potential for contaminated drinking water supplies, the potential for destruction of sensitive ecosystems, and damage to natural resources, among others.

Remedial Investigation/Feasibility Study. After a site is listed on the NPL, a RI/FS is performed at the site.[201] The RI/FS collects data on site conditions and on the nature of the waste, assesses risk to human health and the environment, and conducts treatability testing to evaluate the performance and cost of possible treatment technologies. The FS develops, screens, and evaluates alternative remedial actions.[202]

Record of Decision (ROD). The ROD[203] is a public document that explains which

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196. US EPA, *Guidance for Performing Preliminary Assessments Under CERCLA, Interim Final* (Sept. 1992), (EPA/540-R-92-021) <http://www.hanford.gov/dqo/project/level5/sicercla.pdf> (last visited Dec. 04, 2006).

197. 42 U.S.C. § 9605(c) (2002).

198. US EPA, *Preliminary Assessments/Site Inspection* <http://www.epa.gov/superfund/whatissf/sfproces/pasi.htm> (last visited July 6, 2006); (NTIS PB92-963375, EPA 9345.1-05).

199. US EPA, *Introduction to the HRS* <http://www.epa.gov/superfund/programs/npl_hrs/hrsint.htm> (last visited May 16, 2006).

200. 42 U.S.C. § 9605 (a)(8) (2002); US EPA, *NPL Site Listing Process* <http://www.epa.gov/superfund/sites/npl/npl_hrs.htm> (last visited Feb. 24, 2006).

201. 42 U.S.C. § 9401(a)(1) (1996) (EPA may authorize qualified responsible parties to conduct RI/FS); 42 U.S.C. § 9616 (d) (1996) (RI/FS schedule for initial sites).

202. US EPA, *Remedial Investigation/Feasibility Study* <http://www.epa.gov/superfund/whatissf/sfproces/rifs.htm> (last visited May 16, 2006).

203. US EPA, *Record of Decision* <http://www.epa.gov/superfund/whatissf/sfproces/rod.htm> (last visited May 16, 2006); 40 C.F.R 300.430(f)(5) (2007).

cleanup alternatives were considered and which will be used at the site. The ROD for sites listed on the NPL is based on information from the RI/FS.

Remedial Design/Remedial Action (RD/RA). The RD includes the technical specifications for the remedy and the technologies to be used at the site. The RA follows the RD and includes the construction or implementation of the cleanup.[204] The RD/RA is based on the specifications described in the ROD.[205]

Construction Completion. A site is deemed to have construction completed when physical construction is finished (even if final cleanup levels or other requirements have not been achieved), EPA determines that the response action should be limited to measures that do not involve construction, or the site qualifies for deletion from the NPL.[206]

Post-Construction Completion. In order to ensure that cleanups provide for long-term protection of human health and the environment, several actions may be taken, including operation and maintenance,[207] institutional controls, and five-year reviews. In some cases, a site may be deleted from the NPL if all response actions are complete and all cleanup goals have been achieved.[208]

In summary, the statutory cleanup standards and procedures appear to be general enough that they can apply to nanomaterials. The NCP and the policies and guidance issued under the Superfund program, however, will need to be reviewed to determine if modifications are necessary for purposes of administering the statute in the context of nanomaterial cleanups.

- **Removal or Emergency Response.** The Superfund Emergency Response Program addresses releases of hazardous substances, pollutants, or contaminants into the environment, or substantial threats of such releases, that require immediate or short-term response actions. For example, situations that involve explosions or imminent contamination of a water body may be addressed by the removal or emergency response program. The statute cites fencing or measures to limit access, provision of alternative water supplies, temporary evacuation, and housing as examples of possible components of a removal action.[209] Removals can be performed at non-NPL sites and at sites that are on the NPL, provided the removal contributes to the efficient

204. The Superfund law requires EPA to select remedial actions to carry out the cleanup standards set out in the Act. 42 U.S.C. § 9604(b)(4) (2005).
205. US EPA, *Remedial Design/Remedial Action Handbook* (June 1995), (OSWER 9355.0-04B, EPA 540/R-5/059) <http://www.epa.gov/superfund/whatissf/sfproces/rdrabook.htm> (last visited June 6, 2006).
206. US EPA, *Construction Completion* <http://www.epa.gov/superfund/action/process/ccl.htm> (last visited May 16, 2006).
207. 42 U.S.C. § 9604(c)(6) (2005).
208. US EPA, *Post Construction Completion* <http://www.epa.gov/superfund/action/postconstruction/index.htm> (last visited May 16, 2006); National Contingency Plan guidelines on Deletions, 40 C.F.R Part 300.425(e) (2007)(Guidance for Deleting Sites from the National Priorities List).
209. 42 U.S.C. § 9601(23) (1996).
210. 42 U.S.C. § 9604(a)(2) (2005).

performance of the long-term remedial action at the site.[210]

Similar to long-term remedial actions, the procedures governing removal actions, for the most part, are in regulations, policy, and guidance that would need to be reviewed in order to determine their applicability to removal actions involving nanomaterials. The statute, however, appears broad enough to apply to removal actions when the substances at issue are nanomaterials.

Could the Release Reporting Requirements in the Statute Apply to Nanomaterials?

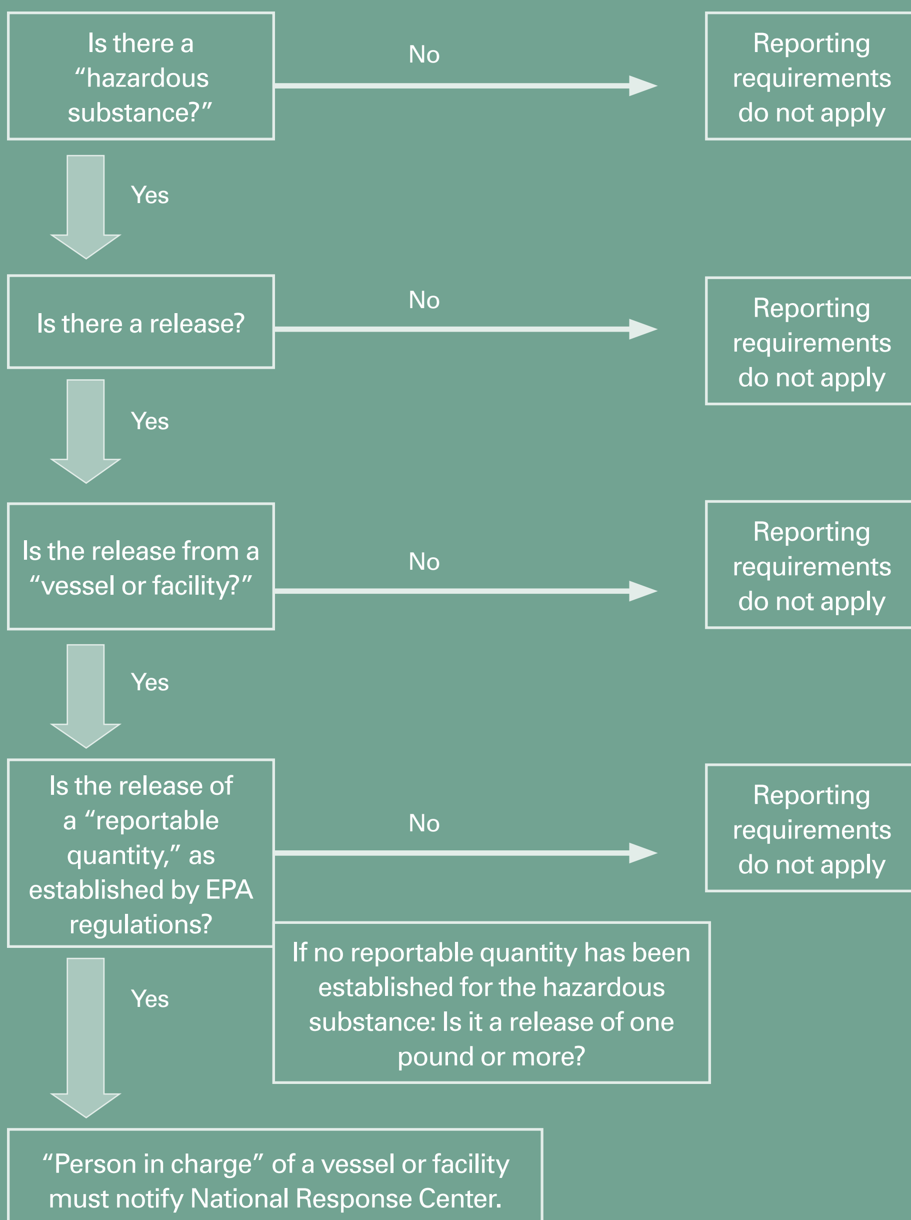
CERCLA contains hazardous substance release notification requirements that are intended to facilitate the identification of sites that may require response actions. Specifically, the statute requires any person in charge of a vessel or facility to notify the National Response Center as soon as he or she has knowledge of any release of a hazardous substance from the vessel or facility, provided the release meets a certain threshold quantity or amount.[211] The statute requires EPA to set by regulation a "reportable quantity" for each hazardous substance. Until a reportable quantity is set for a hazardous substance, the statute states that the quantity of one pound must be used, unless a reportable quantity for the hazardous substance is already established under the Clean Water Act, in which case the latter quantity applies.[212] Substantial civil and criminal penalties are authorized for violations of the reporting requirements.[213]

The statute specifically exempts from the reporting requirements releases that result from application, handling, and storage of certain pesticides,[214] continuous releases for which notification previously has been provided,[215] and releases, the reporting of which are addressed under RCRA.[216] In addition, as noted earlier, certain releases are exempted from the general definition of "release" under the statute because they are covered by other regulatory programs. These include engine exhaust emissions from motor vehicles[217] and federally permitted releases.[218]

Similar to the rest of the statute, the reporting authorities apply to the "release of a hazardous substance." Therefore, the reporting requirements in theory would apply to nanomaterials that constitute hazardous substances under the statute. As discussed above with respect to the definition of hazardous substances, EPA has not designated, through Superfund or any of the statutes referenced by CERCLA, any nanomaterials as hazardous substances. Accordingly, the applicability of the release reporting requirements to nanomaterials will depend in large part on whether EPA takes action now or at a later date, under CERCLA or the other statutes, that results in some types of nanomaterials constituting Superfund hazardous substances. In addition, further analysis could identify nanomaterials that are currently

211. 42 U.S.C. § 9603(a) (1996).
212. 42 U.S.C. § 9602(b) (1996).
213. 42 U.S.C. § 9603(b) (1996).
214. 42 U.S.C. § 9603(e) (1996).
215. 42 U.S.C. § 9603(f) (1996).
216. 42 U.S.C. § 9603(f) (1996).
217. 42 U.S.C. § 9601(22) (1996).
218. 42 U.S.C. § 9601(10) (1996).

Superfund Hazardous Substance Release Reporting



designated as hazardous substances in their bulk form. It is unclear whether such nano-substances would be considered hazardous substances under the statute.

Furthermore, if a nanomaterial is determined to be a hazardous substance, EPA will be required to establish its reportable quantity. Until the reportable quantity is established, the statutory default quantity of one pound may be problematic in the nanomaterial context.

Conclusion

In summary, a review of CERCLA indicates the following:

- The basic elements required for Superfund cleanup authorities to apply—namely, the release of a hazardous substance from a facility into the environment—are broad enough in theory to cover nanomaterials.
- The key threshold issue is whether any nanomaterials are or will constitute hazardous substances under the Superfund statute. This highlights the importance of how EPA assesses and designates nanomaterials not only under CERCLA but also under other statutes that it administers. It also highlights how critically important it is for EPA and private firms to invest in and support, through the various means available, the development and collection of data on human health and eco-toxicity, as these data are lacking in many cases but are an essential component of evaluating nanomaterials as hazardous substances.
- Even if nanomaterials are not hazardous substances, the statute provides broad authority to EPA to address releases of pollutants and contaminants that present an imminent and substantial danger. In theory, this authority could be used to address nanomaterials; however, EPA would be limited to performing the cleanup itself and could not recover its cleanup costs from responsible parties.
- The liability imposed by the statute is far-reaching and could apply to a wide range of parties responsible for nanomaterials, provided the core elements of the statute are met.
- Some of the statutory liability exemptions include a quantity-based element that may not translate well to nanomaterial cleanups; however, these exceptions also contain a toxicity component that in particular cases may suffice to address concerns about quantity-based exemptions.
- The cleanup standards and processes set out in the statute are broad enough to apply to cleanups of nanomaterials. However, if they are to apply effectively to nanomaterial cleanups, EPA will need to review the implementing regulations, policies, and guidance to determine whether amendments are needed to address the unique properties of nanomaterials.
- The release reporting requirements in the statute, in theory, could apply to releases of reportable quantities of nanomaterials, provided the nanomaterials released constitute hazardous substances under the law. The default reportable quantity of one pound may limit the application of the reporting requirements to nanomaterials in cases in which EPA has not established specific reportable quantities.

Recommendations

On the basis of the foregoing analysis of RCRA and CERCLA, the authors recommend the following:

EPA should consider taking the following actions:

- Further invest in and encourage, using the various means available to it, the development of data on human health and eco-toxicity and on the fate and transport of nanomaterials in the environment.
- Conduct outreach and education, particularly to small companies and start-ups, about how the hazardous waste and Superfund programs could apply to nanomaterials, including information about how nanomaterials produced, used, and disposed of today could later be determined to be hazardous substances under Superfund.
- Make decisions about whether and how to apply RCRA and CERCLA to nanomaterials.

Specifically with respect to RCRA:

- Review the four hazardous waste characteristics to determine whether they remain appropriate in light of the potential that waste nanomaterials may have properties and functions that differ substantially from those of bulk wastes.
- Review the Toxicity Characteristic Leaching Procedure to determine whether it accurately predicts the fate and transport of nanowastes disposed on land, and revise it if necessary.
- Consider whether specific nanowastes, or categories of nanowastes, should be listed as hazardous wastes.
- Consider whether specific nanowastes, or categories of nanowastes, should be classified as acute hazardous wastes subject to the 1-kilogram-per-month accumulation rule for generators.
- Conduct research to determine whether existing practices for handling, treating, storing, and disposing of bulk forms of solid wastes are appropriate for nanoscale wastes of the same chemicals.

Specifically with respect to CERCLA:

- Determine whether any current Superfund hazardous substances are produced in nanoform and, if so, assess whether these substances also are hazardous in nanoform and, therefore, covered by the Superfund program.
- Assess whether to use its authority under the Superfund law to evaluate nanomaterials for purposes of determining whether they are hazardous substances.
- Take into account that actions that affect nanomaterials under other statutes it administers could indirectly result in the addition of a nanomaterial to the list of Superfund hazardous substances.

Private firms that are handling nanomaterials today should consider taking the following actions:

- Apply the RCRA hazardous waste rules to nanomaterials, including determining when they become wastes, determining whether those wastes meet the definition of hazardous waste, and managing hazardous wastes as required.

- Recognize that even if nanomaterials do not constitute hazardous wastes under RCRA, at a later date they could be determined by EPA to be hazardous substances under Superfund.
- Dispose of nanomaterials in a manner that accounts for the possibility that they could later be strictly and jointly and severally liable to the government or liable to private parties, if those nanomaterials subsequently are released, or there is a substantial threat of their release, from a facility into the environment.
- Recognize that as a result of CERCLA, RCRA, and other environmental statutes, the environmental due diligence that accompanies many commercial transactions and securities offerings could examine their handling and disposal of nanomaterials.
- Join with universities and government in promoting and conducting research on human health and eco-toxicity of nanomaterials, their fate and transport in the environment, and appropriate methods of handling, treating, storing, and disposing of waste nanomaterials.

Insurance companies (and their insureds) should consider taking the following actions:

- Take into account the potential environmental risks and liabilities posed by releases or disposal of waste nanomaterials and products in drafting new policies, interpreting existing policies, and planning for future potential liabilities.

Banks in making lending decisions should consider taking the following actions:

- Take into account the potential environmental risks and liabilities posed by releases or disposal of waste nanomaterials and products.

Venture capital and investment firms in making investment decisions should consider taking the following actions:

- Take into account the potential environmental risks and liabilities posed by releases or disposal of waste nanomaterials and products.

Appendix: Solid Waste Programs at the State Level

RCRA directs states in the design, management, and operation of solid waste programs (sometimes called the Subtitle D program). The statute provides guidelines for states in establishing programs, facilities, and appointing a management authority for solid or non-hazardous wastes.[219] EPA has promulgated more-detailed regulations and guidelines that constitute the solid waste program (SWP).[220] The SWP includes provisions for all waste types that are not included in the definition of hazardous wastes, though some hazardous wastes are either permanently or temporarily regulated under the SWP. Types of wastes covered include, but are not limited to, household waste, municipal waste, industrial waste, mining waste, and medical waste. The regulations include detailed standards for comprehensive waste management regulations and waste facility criteria for states. All areas of solid waste management, including waste identification, collection, sorting, reuse, combustion, treatment, disposal, facility siting, and transportation, are covered within the solid waste program. The regulations also direct states to take a broad view, "[t]he State plan shall address all solid waste in the State that poses potential adverse effects on health or the environment or provides opportunity for resource conservation or resource recovery."[221]

The federal guidelines for solid waste disposal begin with a directive for each governor to establish regions for waste management based on urban concentrations, geographic conditions, and markets. The states must then choose a department or agency to develop a plan, and then direct the same or an additional agency to execute and distribute responsibilities among state, regional, or local bodies.[222] EPA considered a wide variety of factors related to solid waste in developing the guidelines for state plans, including states' solid waste generation trends and the physical characteristics and capabilities of the state.[223] The guidelines also take into account "the varying regional, geologic, hydrologic, climatic, and other circumstances under which different solid waste practices are required in order to insure reasonable protection of the quality of the ground and surface waters from surface water contamination."[224]

Congress had a particular concern for protecting human health and the environment from groundwater contamination. Therefore, the guidelines also include monitoring requirements and corrective action directives for the protection of groundwater resources from leaking solid waste landfills.[225] Congress also recognized that guidelines were needed for solid waste facilities that may receive hazardous

219. 42 USC §§6946 and 6942 (1996).
220. 40 C.F.R. Parts 239 – 259 (2007).
221. 40 CFR §256.02(a)(1) (2007).
222. 42 USC §6946(a)&(b) (1996).
223. 42 USC §6942(c)(1-11) (1996).
224. 42 USC §6942(c)(1) (1996).
225. 42 USC §6949a.(c)(3)(A-C) (1996) and 40 C.F.R. §§257.21-29 (2007).

Q-Dot: The Interaction of Waste Regulatory Programs

The Q-Dot hypothetical raises the issue of the relationship between the solid waste and hazardous waste regulatory programs. As a conditionally exempt small quantity generator of hazardous waste (generates less than 100 kg/month of hazardous waste) Q-Dot is allowed to ship its hazardous waste to a solid waste facility. This is one aspect of the general assumption on which the hazardous waste program is based; namely, that risks from hazardous waste are directly related to the quantity of waste (special provisions for acutely hazardous wastes recognize that some wastes are hazardous in small quantities). Q-Dot has complied with the requirements for choosing an appropriate solid waste landfill.

household waste and hazardous wastes from small quantity generators. Minimum requirements for such facilities include groundwater monitoring to detect contamination, siting criteria, and corrective action when there is a release of hazardous wastes.[226]

The SWP regulations establish criteria for waste disposal facilities, such as their impact on endangered species, habitat maintenance, and groundwater. The rules include criteria for waste landfills and provide states with location, operation, design, monitoring, closure, corrective action, and financial instructions and stipulations for the sites.[227]

The SWP regulations set minimum adequacy and performance standards regarding state permitting programs for solid waste disposal facilities, and outline requirements for permit applications. A state may exceed these standards, but it must apply to the appropriate EPA Regional Director for a determination of adequacy of its permit program.[228]

The SWP provides thorough guidelines for thermal processing of waste. These guidelines have minimum performance standards as well as preferred methods for state operations.[229] The federal regulations authorize the owner/operator of the facility to exercise discretion over what materials can be burned at a facility,[230] while many of the design and operation procedures are merely suggested. However, the air-quality standards are mandatory and capped at the more stringent of federal Clean Air Act standards or state/local emission standards.[231]

The federal regulations delineate the necessary safety and health standards for Solid Waste Generators (SWG).[232] These guidelines apply to municipal, household, and institutional waste, while excluding mining, agricultural, and industrial solid wastes; hazardous wastes; sludges; construction and demolition wastes; and infectious wastes. The SWP guidelines also address source separation for resource recovery, with the same inclusions and exclusions. These guidelines also contain recycling and reuse requirements for certain SWGs, such as high-grade paper. [233]

226. 42 USC §6949a.(c)(1) (1996).
227. 40 CFR Part 258 (2007).
228. 40 CFR §239.2 (2007).
229. 40 CFR Part 240 (2007).
230. 40 CFR § 240.200.1 (2007).
231. 40 CFR § 240.205.1 (2007).
232. 40 CFR Part 243 (2007).
233. 40 C.F.R. Part 246 (2007).

It is the responsibility of the landfill operator to meet the siting, design, operation, monitoring, and corrective action requirements, which would be set and overseen by the state. Under normal circumstances, the state would require the landfill operator to undertake corrective action with respect to the contamination of the groundwater, which typically would obviate any need to involve the Superfund Program or Q-Dot or other generators. Solid waste landfills, however, were not designed to prevent the release of nanomaterials. They may be effective in preventing the release of nanomaterials, but no research has been done to investigate what types of design will be effective for nanowastes.

List of Acronyms

AEA – Atomic Energy Act
CERCLA – Comprehensive Environmental Response, Compensation, and Liability Act
CESQG – Conditionally Exempt Small Quantity Generator
DOT – Department of Transportation
ELI – Environmental Law Institute
EPA – Environmental Protection Agency
FIFRA – Federal Insecticide, Fungicide, and Rodenticide Act
HRS – Hazard Ranking System
MSW – Municipal Solid Waste
NCP – National Contingency Plan
NNI – National Nanotechnology Initiative
NPDES – National Pollutant Discharge Elimination System
NPL – National Priorities List
PA/SI – Preliminary Assessment/Site Inspection
POTW – Publicly Owned Treatment Works
RCRA – Resource Conservation and Recovery Act
RD/RA – Remedial Design/Remedial Action
RI/FS – Remedial Investigation and Feasibility Study
ROD – Record of Decision
SQG – Small Quantity Generator
SWG – Solid Waste Generator
SWP – Solid Waste Program
TCLP – Toxicity Characteristic Leaching Procedure
TSCA – Toxic Substances Control Act
TSDF – Treatment, Storage, or Disposal Facility

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Reports

PEN 1: Jane Macoubrie, *Informed Public Perceptions of Nanotechnology and Trust in Government*, September 2005.

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Congressional Testimonies

David Rejeski, "Environmental and Safety Impacts of Nanotechnology: What Research Is Needed," United States House of Representatives, Committee on Science, November 17, 2005.

J. Clarence Davies, "Developments in Nanotechnology," United States Senate, Committee on Commerce, Science and Transportation, February 15, 2006.

David Rejeski, "Promoting Economic Development Opportunities Through Nano Commercialization," United States Senate, Committee on Commerce, Science and Transportation, Subcommittee on Trade, Tourism and Economic Development, May 4, 2006.

Andrew D. Maynard, "Research on Environmental and Safety Impacts of Nanotechnology: What Are the Federal Agencies Doing?," United States House of Representatives, Committee on Science, September 21, 2006.

Inventories

Nanotechnology Environment, Health and Safety Risk Research, released November 2005.

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