to carry any chemical compounds after surface modification, offers carbon nanotubes the potentials to be used as nanoscale catalysts with high catalytic reactivity and chemical sensors. They are known to be the best field emitters due to their sharp tips, which can concentrate electric field easily, enabling them to emit electrons at low voltages.

This property has special applications in field emission flat-panel displays and cold-cathode electron guns used in microscopes. In nanoelectronics, SWNTs have been used to fabricate transistors that can function at room temperature, and are potential candidates for devices operating at terahertz (THz) frequencies. Engineering materials using carbon nanotubes as additives have exhibited capability to make plastic composites with enhanced electrical conductivity and mechanical strength. For biomedical applications, carbon nanotubes show promise as vehicles for targeted drug-delivery and nerve cell regeneration. However, their future success in bio-related applications is highly subject to the toxicity study, which is still at early stage.

Some researchers have become concerned about the health risks involving carbon nanotubes, which according to lab research seem to pose a danger to human health that is similar to asbestos. In particular, exposure to carbon nanotubes has been associated with mesothelioma, a cancer of the lung lining. If inhaled, it is believed that nanotubes can scar lung tissues in a manner similar to asbestos fibers, a cause for concern because nanotubes are already used in many common products, such as bicycle frames, automobile bodies, and tennis rackets. Potential health risks are relevant not only to those involved in manufacturing, but also to the general public, and research has not yet been conducted to determine if risks to human health are created when products containing nanotubes are crushed or incinerated in a waste dump.

See Also: Fullerene; Nanoelectronics; Nanomaterials; Nanotoxicology.

Further Readings


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Center for Biological and Environmental Nanotechnology

Public policy with regard to nanotechnology has at times been curiously bifurcated. To a first approximation, policy for nano has been directed largely toward establishing interdisciplinary centers to aid university-industry cooperation in electronics and, increasingly, medicine. Policy debates about nanotechnology, on the other hand, have largely revolved around potential risks to health and the environment, and public perceptions of those risks. One of the first and most important institutions at the intersection of policy for and policy about nano is the Center for Biological and Environmental Nanotechnology (CBEN) at Rice University.

CBEN was the product of a convergence of two coalitions in the late 1990s, one local to Rice and one national in scope but located largely at the U.S. National Science Foundation (NSF) and the U.S. National Nanotechnology Initiative (NNI). Two key figures mediated between these coalitions: Richard Smalley, the Nobel laureate chemist and codiscoverer of the buckyball; and Neal Lane, a physicist, former Rice provost and NSF director, then science advisor to President Bill Clinton. Over the course of his career, Smalley built up a large institutional base for nanotechnology at Rice, encompassing more than a quarter of the school's science and engineering faculty. He did so initially through his directorship of the Rice Quantum Institute, then by founding the Center for Nanoscale Science and Technology (CNST) in the mid-1990s. Smalley's vision for what nanotechnology would be—a convergence of science and engineering and a catalyst for commercialization of academic research—clearly informed Lane's support for efforts to build a National Nanotechnology Initiative. In addition, Smalley had a large presence on the national science
policy scene, and his CNST was taken as a model for the first round of Nanoscale Science and Engineering Centers funded by the NSF.

By the late 1990s, Smalley hoped to get NSF funding for a Center for Carbon Nanotechnology at Rice. This proposal was turned down, however, partly because reviewers felt it would take Smalley away from his research. So when two younger Rice faculty, Vicki Colvin and Mark Wiesner, presented a proposal to run a Center for Biological and Environmental Nanotechnology, Smalley became its champion.

The Good, the Bad, and the Ugly
Smalley's vision for CBEN differed somewhat from Colvin and Wiesner's, however. Smalley wanted a center focused on molecular electronics or nanoelectronic devices, for which he was recruiting faculty such as James Tour. Colvin, who had initially become interested in a Center as a way to bring expensive instrumentation such as a transmission electron microscope to Rice, thought that other universities were too far ahead of Rice in electronics, but that Rice's reputation in environmental and bioengineering was strong enough that a center proposal in that area would have a good chance.

This spurred Colvin to recruit Wiesner and other Rice engineers, such as Jennifer West, to join the CBEN proposal. Both Wiesner and West pointed out that, because of U.S. Federal Drug Administration (FDA) and U.S. Environmental Protection Agency (EPA) regulation, the toxicology and environmental impacts of any nanoparticles researched at CBEN would have to be understood for commercialization of that research to succeed. Wiesner, in particular, insisted that CBEN should make the potential impacts of nanotechnology a central focus, much to Smalley's dismay. Smalley, meanwhile, insisted that CBEN focus on the "wet/dry interface," that is, materials that combined biomolecules or biological systems with the crystals and inorganic molecules more often studied by materials scientists and device physicists.

In the end, Colvin's suspicion that the NSF would receive many proposals for molecular electronics centers but only one proposal for biological and environmental nanotechnology was borne out. Reviews of the proposal, both positive and negative, focused on Wiesner's emphasis on potential risks of nanoparticles, with some reviewers seeing the benefits of such an approach and others fearing that it would expose the nanotechnology enterprise to criticism. It is important to remem-
ber that at the turn of the millennium, research into nanotechnology's risks was controversial, whereas even a few years later it was seen as common sense. Although CBEN alone did not cause that transformation, it was one of the first and most important institutions in perceiving—and then effecting—that shift.

Coproduced With a Community
From the outset, therefore, CBEN research has been delicately balanced: projects that seek to use nanotechnology to improve health or ameliorate environmental damage on the one hand, and projects that seek to understand potential harms from nanoparticles on the other. Sometimes, both kinds of projects coexist in one lab. Colvin's group, for instance, has invented magnetite nanoparticles capable of removing arsenic from drinking water, while at the same time researching the ecotoxicology of engineered nanoparticles. Initially, CBEN's lab research fell into three broad streams: nanoscience at the wet/dry interface; nanoparticles that detect and treat disease; and effective, high-performance water purification systems. These corresponded, roughly and respectively, to the expertise of Colvin, West, and Wiesner, though each stream also included several other researchers. CBEN also included a large program in education and outreach, commercialization, and policy analysis. All NSF-funded centers at the turn of the millennium were under pressure to include such components, but CBEN's mission makes these functions integral to its success. CBEN people often refer to past technologies as having undergone a "wow to yuck" trajectory, that is, technologies that are oversold at the beginning end up facing a backlash later on. CBEN was intended to leaven that trajectory—to be forthright and curious about potential risks at the beginning, in order to avoid a backlash. Injecting CBEN's findings into public and policy discourse about nanotechnology is necessary for that leavening to take place.

Integration into wider discourse has taken a number of forms: humanists and social scientists have been included in CBEN research from early on; courses on nanotechnology and society have reached large numbers of undergraduates; and industrial affiliates and entrepreneurship programs have aided commercialization. In 2005, CBEN spun off a semi-independent International Council on Nanotechnology (ICON) to mediate among various stakeholders (corporate, government, academic, and nongovernmental organizations) in nanotechnology and to foster and disseminate nanotoxicology research.
Finally, CBEN has maintained an active presence on the national and international scene through, for instance, Colvin’s repeated appearances on Capitol Hill and various CBEN researchers’ memberships in international coordinating bodies. When CBEN was founded, the field of nanotoxicology did not exist. Those few researchers interested in the topic had no institutions to cohere them into a community. CBEN has certainly not been the only such institution, but it was one of the first and most important, and it spawned numerous peers, competitors, and successors.

See Also: Center for Environmental Implications of Nanotechnology; Environmental Benefits; Interdisciplinary Research Centers; Nanotoxicology; Smalley, Richard.

Further Readings
Colvin, Vicki L. Testimony to U.S. House Committee on Science and Technology, Subcommittee on Research and Science Education (October 31, 2007).

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Center for the Environmental Implications of Nanotechnology

The Center for the Environmental Implications of Nanotechnology (CEINT) was an early attempt to ensure that the exponential growth of nanotechnology is well ordered and does not impact the environment in adverse ways. The Center is thus an anticipatory response drawing upon lessons from previous technological innovations such as asbestos, DDT and chlorofluorocarbons that were initially hailed as technological panaceas but were later found to have had serious environmental impacts. There are concerns that nanotechnology could be a similar double-edged sword.

The Center evaluates a vast array of nanomaterials—from natural, to manufactured, to those produced incidentally by human activities—and their potential environmental exposure, biological effects, and ecological consequences. Headquartered at Duke University, CEINT is a partnership between Duke (Pratt School of Engineering, Nicholas School of the Environment, Nicholas Institute for Environmental Policy Solutions, Trinity School of Arts and Sciences), Carnegie Mellon University, Howard University, Virginia Tech, the University of Kentucky, and Stanford University. CEINT academic collaborations in the United States also include on-going activities coordinated with faculty at Clemson, North Carolina State, Rice, University of California, Los Angeles (UCLA) and North Carolina Central universities, researchers at the U.S. National Institute of Standards and Technology (NIST) and the U.S. Environmental Protection Agency (EPA) government labs, and with key international partners.

On the West Coast, the main headquarters of CEINT is at UCLA, where the California NanoSystems Institute (CNSI) serves as the major base of operations for CEINT, with a second major hub at University of California, Santa Barbara. Created in 2008 with funding from the U.S. National Science Foundation (NSF) and EPA, CEINT performs fundamental research on the behavior of nanoscale materials in laboratory and complex ecosystems. This research encompasses all aspects of nanomaterial transport, fate and exposure, as well as ecotoxicological and ecosystem impacts. One of the key areas of CEINT expertise is in the development of risk assessment models that are expected to give investigators the proper tools to evaluate and assess extant and future concerns that may arise regarding the environmental implications of nanomaterials. The research focus at the University of California Center for Environmental Implications of Nanotechnology (UCCIONI) is ensuring that nanotechnology is environmentally compatible and safe, and UCCIONI has developed a broad-based predictive toxicology model premised on quantitative structure–activity relationships (QSARs) as determined by looking at nanomaterial injury mechanisms at cellular, tissue, organism and mesocosm levels.

Among the U.S. government agencies that the Center collaborates with are NIST, EPA, Pacific Northwest National Laboratory/Environmental Molecular Science Laboratory /U.S. Department of Energy, U.S. Army Corps of Engineers Engineer Research and Development Center (ERDC), and the National Institute of Environ-