Center for Biological and Environmental Nanotechnology (CBEN)

NSF NSEC Grant 0118007
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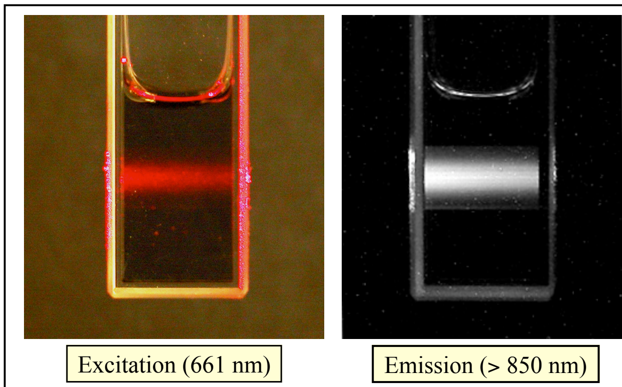
Our mission is to create sustainable nanotechnologies that improve human health and the environment. We do this by:

- **Fundamental examination of the 'wet/dry' interface** between nanomaterials and complex aqueous systems (Theme 1).
- **Interdisciplinary systems-level research** that combines nanochemistry, environmental and bioengineering to develop new nanotechnologies (Themes 2,3).
- **Developing sustainable nanomanufacturing systems** which provide at low cost and high volume the nanomaterials needed for testbeds and prototypes.
- **Innovative knowledge transfer activities** that recognize the central role that the academic entrepreneur plays in technology development.
- **Educational programs that develop teachers, students and citizens** who are well informed and enthusiastic about nanotechnology.

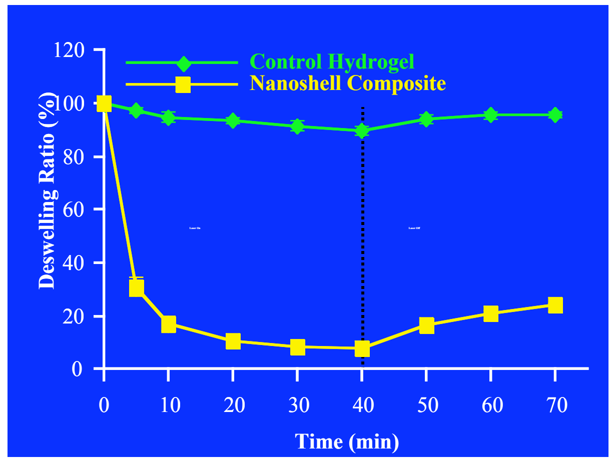
We believe that through control over the wet/dry interface, nanomaterials will be positioned to revolutionize how we detect and cure disease, as well as how we clean our water and waste streams. Organizations such as ours must develop the collaborative research, human resources, and commercial technologies that lay the foundation for this revolution.

In our center's relatively short existence we can claim many diverse research accomplishments ranging from the discovery of carbon nanotube near-infrared emission to a novel drug delivery scheme. Our efforts in theme 1 focus on the control and understanding of water-soluble inorganic nanostructures. Projects range from the controlled assembly of metal nanostructures using DNA-recognition proteins to the interaction of nanoparticles with living organisms. One example work from this theme area was just recently featured in Science [ref]. Weisman and coworkers reported the remarkable observation of near-infrared emission in isolated single-walled carbon nanotubes suspended in water. This discovery was made possible by creating a wet/dry interface at the hydrophobic nanotube surface via surfactants; molecular dynamic models of the surfactant/SWNT assemblies were an essential step for optimizing this solubilization scheme. Unlike aggregated nanotubes, these materials have structured near-infrared emission spectra. It is a sensitive measure of nanotube type and diameter, exhibiting a tunability of optical properties reminiscent of quantum dots. Because near-infrared light is minimally absorbed in the body, we



Near-infrared Photoluminescence from SWNTs are quickly transitioning the basic nanochemistry and spectroscopy into potential biomedical technologies which exploit the emission for disease detection.

Biomedical technologies represent a major thrust area in our center. Biomaterials must be multifunctional, biocompatible and high performance for most medical applications; nanomaterials with a properly engineered wet/dry interface offer solutions to many of these demanding requirements as well as entirely new ways of treating disease. West and Halas have developed gold nanoshell materials which absorb strongly in the near infrared; the near-infrared wavelengths are an idea range for medical applications since such light can penetrate quite deeply into human tissue. Thus, these particles can absorb the light causing localized heating in specific areas. When incorporated into thermally sensitive polymers embedded into tissue, external light can heat locally the polymer and thus trigger the release of drugs. Such 'intentional release' drug packages are well suited for patient controlled dosing of insulin, for example. We also develop nanocomposite materials with both structured meso- and macorpores as well as inorganic fillers for tissue replacement. In particular, a biodegradable and injectable polymer when filled with 10-20 wt% nanoparticles can exhibit superior mechanical properties. This widens the applications of injectable polymers in bone replacement.

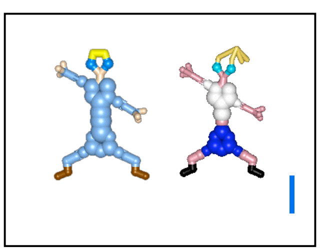


The enabling technologies which surround the wet-dry interface also can be used to solve problems in environmental engineering. Wiesner and Colvin have reported new types of membrane architectures for filtration based around template-assisted chemistries. By relying on the chemical tuning of colloidal crystallization and aggregation, templates of varying levels of porosity and pore size can be fabricated. With morphologies spanning multiple length scales (nanometers to micrometers), modeling by Pasquali suggests that such architectures are well suited for filtration applications where surface fouling is a significant issue. Other anti-fouling technologies rely on the presence of mobile and solution phase nanoparticles to getter inorganic contaminants. Barium sulfate, a contaminant which can cause scaling and disruption of many separation processes especially involving sea water, can be removed quite efficiently by treatment with modest levels of nanoscale titanium dioxide. Multifunctional membranes, that both separate and treat waste, have also been generated by CBEN scientists, Wiesner and Barron. Such ferroxane membranes cast from iron oxide nanoparticles can be used for catalytic waste treatment as well as industrial separations.

With our focus on environmental issues in nanotechnology, it is quite natural for us to be concerned about the sustainability and environmental impact of the core nanomaterials in our center. A portion of our environmental engineering research addresses this concern directly. Several long range CBEN projects have as their goal the development of a risk assessment model for nanomaterials. Environmental engineers are using well-characterized and controlled nanoparticles to extend existing models of colloidal particle transport down into the nanoscale regime. Additionally, biodegradation processes are essential for determining the persistence time of materials in waters and soils; preliminary data indicates that in the case of carbon-based systems biodegradation is possible. Finally, we are characterizing the potential for nanoscale materials to enhance transport of known contaminants through physical and chemical sorption. The data show that while nanoscale particles have high surface areas, their more uniform and perfect structures minimize the active sites for such attachment relative to larger, less perfect colloidal matter.

Because many of our systems-level goals involve nanoparticles as key components, we recognized early on the need for addressing problems with creating larger quantities of materials for testbeds. Rather than simply scale-up existing preparative methods, we are teaming our nanochemists and chemical engineers to create fundamentally new paradigms for nanomaterial synthesis. Our goals are to develop continuous-flow processing methods which allow for solvent-recycling and include post-preparation size-selection schemes to ensure nanomaterial quality. Modeling and simulation of nanoparticle growth is essential to this effort in that it guides reactor design. Using size exclusion chromatography we have started to separate nanocrystals by size preparatively, and have generated data concerning the reactive species in the solution as time progresses. Such inputs provide the avenue for population balance models of the growth process and allow us to develop a model to optimize before starting experiments. This project area receives substantial industrial interest and is our primary mode for interacting with affiliates in the speciality chemical industry. Our larger industrial affiliates program is flexibly designed to allow industries with an interest in nanotechnology benefit from our expertise in nanomanufacturing, environmental technologies and medical applications.

One important role for a center is to serve as a node for the larger nanotechnology community and provide for specialists, media and the public overviews and up-to-date information in its areas of expertise. CBEN has developed such a network in the important and emerging area of nanotechnology and the environment. Since our inception we have sponsored a number of workshops in the topic, and provide on our web page links to a variety of resources in this new topical area. We have been active in media interactions as well on the general topic of the possible environmental implications with the aim of controlling the potential backlash against nanotechnology. Finally, we have reached out to other government agencies such as EPA and NIEHS with the aim of developing the necessary toxicological data to pair with the fundamental studies of nanomaterials fate and transport in the environment.



Our educational initiatives lay the groundwork for developing the nanotechnology workforce of the future. One program recently highlighted in the popular press is the Nanokids™ effort led by chemist, Jim Tour. This project teaches chemical principles through anthropomorphic molecules; while this is a challenging prospect, the use of kid-friendly icons, nano-boy and his friends, opens up the possibility of telling the story of chemistry through characters kids and parents can relate to. We are incorporating interactive story lines which connect to the existing curriculum in the hopes that the visual aids will create a teachable moment for students. This effort in developing educational materials is complementary to our year-long teacher training program. Through structured and unstructured interactions with the center, teachers learn basic concepts as related to the Texas science curriculum through examination of relevant nanoscience problems. An abbreviated version of this program for teachers from distant, rural school districts which serve diverse populations is also available, as are summer programs for high school and college students. New degrees in nanotechnology and environmental decision-making have driven many new courses in nanotechnology typically team taught by faculty from across campus.

For more information about CBEN and these projects, as well as a publication list, please see http://www.ruf.rice.edu/~cben/.