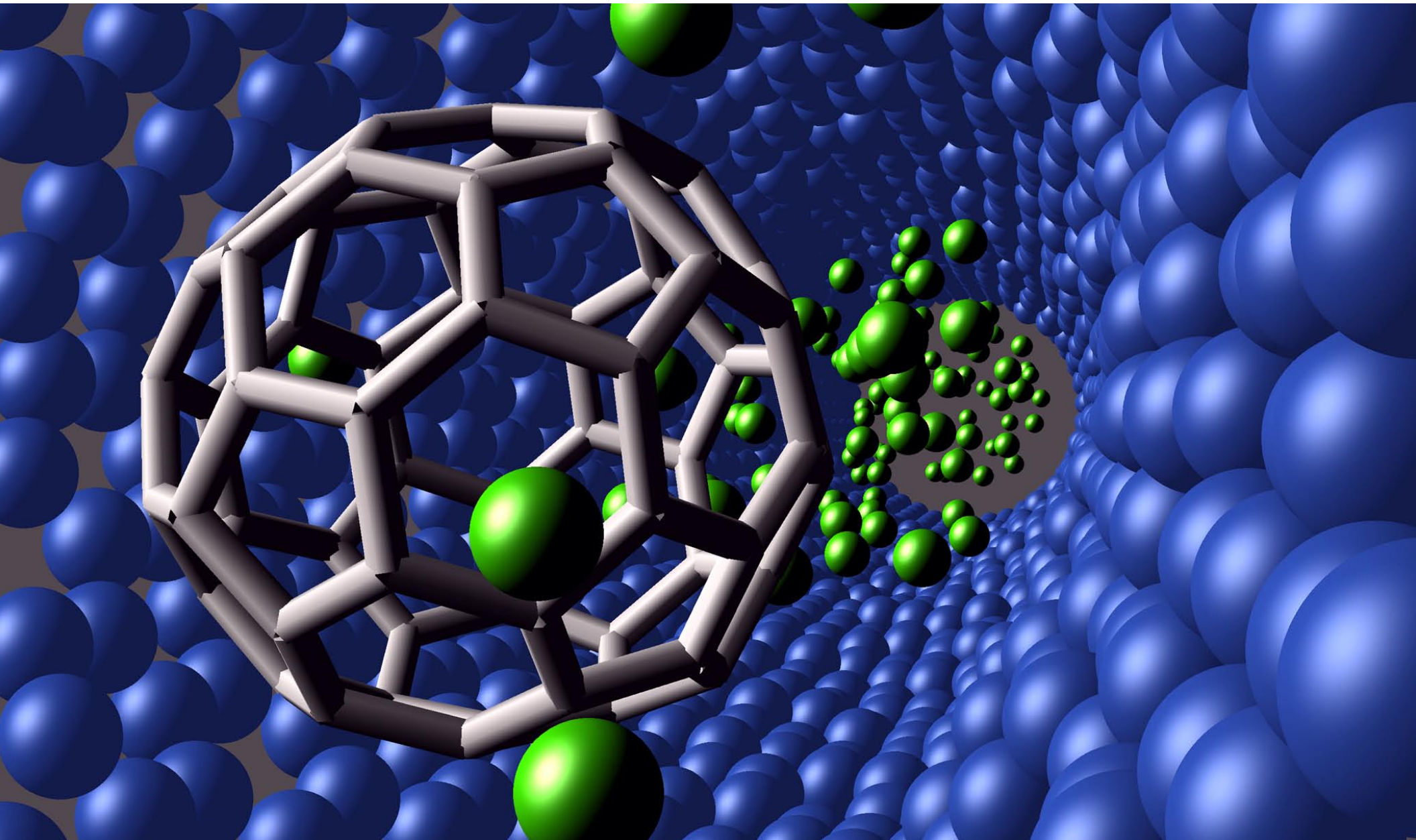


Nanoscience



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Nanoscience Challenges

Nanoscience is revolutionizing products in many industries. While this brings opportunity for new and improved products and technologies, the increased use of nanomaterials also has increased concern about their safety and environmental impact. Industry and regulatory agencies have recognized that there are many scientific challenges associated with ensuring responsible use of nanomaterials, which will allow us to enjoy their benefits while still **protecting human health and safeguarding the environment.**

At Battelle our experts are working to solve the challenges associated with nanomaterials. Our multidisciplinary teams include leaders in the development and application of novel nanomaterials; experts in nanotoxicology; specialists in human and environmental exposure and risk assessment; state-of-the-art facilities and instrumentation for nanomaterial characterization; environmental fate and transport experts; as well as leaders in encouraging responsible development of nanomaterials and in incorporating nanotechnology into policy-making and planning. The following project examples are centered on these areas of expertise and illustrate how Battelle provides innovative solutions to advance nanoscience.



Health/Ecological Effects of Nanomaterials

Systems Toxicology of Nanomaterials

Battelle is developing an integrated capability, including tools and scientific expertise, to predict toxicity of nanomaterials to aid in guiding development, commercialization, and regulation of safe nanomaterials. Research focuses on biosignature identification based upon characterizing properties of nanomaterials, novel imaging approaches to describe the molecular and cellular fate of nanomaterials, and systems toxicology-based integrative approaches to identify molecular mechanisms of toxicity. This integrated approach facilitates understanding nanomaterials' properties that lead to toxicity and will advance the field of biomarker discovery for environmental respiratory tract diseases associated with nanomaterial exposure.

Projects start with the design, synthesis, and characterization of nanoparticles used for imaging and biological response projects. Imaging studies are carried out to elucidate cellular fate and processing of nanomaterials. These results then are used in conjunction with computational and experimental dosimetry to determine actual exposure of cells during in vitro and in vivo

studies on biological response. Molecular and pathway analysis tools are used to understand cellular or tissue processes. Subsequently, predictive computational tools are used to relate nanomaterial characteristics to biological response.

Specific projects to help answer questions about engineered nanomaterials and their impact on human and ecosystem health include the following:

- Discovery of a Biomarker Signature in Response to Nanoparticle Exposure
- Model Nanoparticles for Discovery and Validation of PM Biomarkers
- Nanomaterial Exposure and Respiratory Effects Biosignature Discovery
- Nanoscale Insight into the Living Cell Membrane Responses to Ultrafine PM
- Non-Invasive Real-Time In Situ Spectroscopic Monitoring of Macrophage-Particulate Matter Interactions
- Secretome Analysis of Environmental Particulate Matter Induced Biomarkers
- Signatures of Oxidative Stress Associated with Inhaled Particulate Matter

Additional information is available at http://biomarkers.pnl.gov/fa_stox.asp.

Nanoparticle Inhalation Toxicology

Battelle's Toxicology Northwest is the nation's leader in inhalation toxicology of vapors, particulates, nanomaterials, and fibers. Here, aerosol scientists realized their most recent innovation—the first controlled generation and real-time monitoring of micron and nanoscale C60 fullerene for chronic inhalation exposure. This important advancement in inhalation exposure technology overcame significant technical challenges and limitations to create the state-of-the-art system for conducting in vivo exposure to nanomaterials. This ideal exposure system for human hazard and safety assessment is being used by the National Toxicology Program and illustrates our unmatched experience conducting chronic toxicity studies of ultrafine particulates and fibers. This nanoparticle inhalation work was published in the *Journal of Aerosol Science and Toxicological Sciences*. Additional information is available at <http://www.pnl.gov/nanotoxicology/>.

Flow Reactor Modeling for Nanoparticle Generation

Battelle developed modeling capabilities to simulate nanoparticle synthesis in process flow reactors. The tools of conjugate heat transfer computational fluid dynamics (CFD) are applied to gain a better understanding of the critical flow parameters such as temperature profile, condensation rate, and aerosol residence time that impact the final product nanoparticle quality. The modeling also guided design enhancements that reduced the variability in size distribution. Furthermore, an internal research program conducted to implement a general dynamics equation for aerosol evolution and transport into the CFD model provided more insight into the physical processes governing nanoparticle creation. Model simulation results for particle tracking in the generation chamber are depicted for simulation of a flow reactor using flash vaporization followed by nitrogen condensation to generate C60 nanoparticles used in inhalation toxicology exposure tests. A sample model simulation is shown in Figure 1.

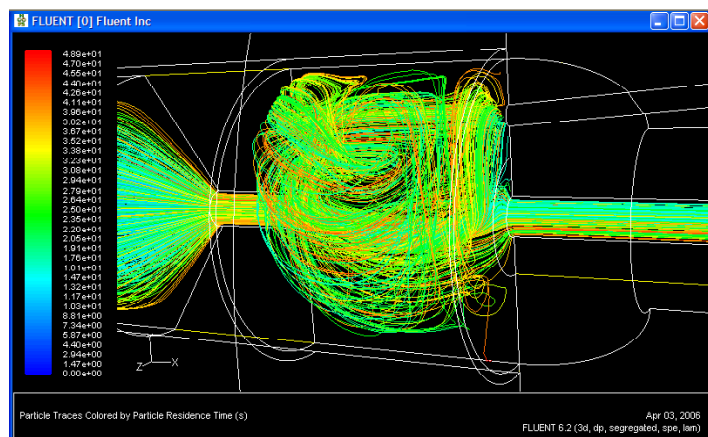


Figure 1. C60 nanoparticle traces colored by residence time

Fate and Transport of Titanium Dioxide Through Freshwater Ecosystems

Characterization and quantification of titanium dioxide (titania, TiO_2) nanoparticles in a flow-through bench-scale aquatic system is being used to incorporate different environmental media (i.e., water, sediment, and benthic/sediment dwelling invertebrates) to monitor the fate and transport of the material. Nanomaterial partitioning and complexation in water, sediment, and tissue media will be characterized using inductively coupled plasma mass spectrometry and scanning electron microscopy with energy dispersive X-ray spectroscopy, respectively. The data sets derived from this work will build the foundation for future use in fate and transport of other nanomaterials in different aquatic systems (i.e., freshwater, estuarine, and marine) and in building process and empirical models that can be used to investigate environmental fate and transport and the ecological impact of nanomaterials.

Featured Staff

Dr. Joel Pounds is a Senior Staff Scientist in Cell Biology and Biochemistry, Biological Sciences Division, and Science Advisor to the Environmental Biomarkers Initiative. Dr. Pounds has directed research programs in government, National Laboratories, and academia. His research focuses on the cellular and molecular toxicity of lead and other metals, metal-metal interaction, and mathematical modeling of the response to metal mixtures. Dr. Pounds' current research includes use of mass-spectrometry-based proteomic and NMR-based metabolomic instrumentation for characterization of biological responses to airborne toxicants including nanomaterials.

Dr. Gregory Baker is a study director/toxicologist and the main point of contact in support of contract research inhalation toxicity studies performed under good laboratory practices (GLP) at Battelle Toxicology Northwest. Dr. Baker is Battelle's acting National Toxicology Program (NTP) discipline leader and served as Project Manager for Battelle's internal research and development project on inhalation nanotoxicology.

Mr. Amit Gupta designs and supervises construction and testing, validates and documents exposure systems for aerosol inhalation toxicology studies, and is the lead engineer responsible for developing and validating the C60 nanoparticle generation system used to conduct the first-ever inhalation toxicity study on C60 nanoparticles noted above. Additionally, Mr. Gupta has assisted in other aerosol inhalation studies including those for Cobalt powder, metal working fluids (Cimstar 3800, Trim 2210, etc.), and abrasive blasting sands. Currently Mr. Gupta is Project Manager for a sanding study of a Multi-Walled Carbon Nanotube (MWCNT) impregnated nanocomposite.

Mr. David Hesse has 25 years' experience in process simulation and system modeling for Battelle's Applied Biology and Aerosol Technology group. He researches and develops computational fluid dynamics models for aerosol synthesis and transport applications. Mr. Hesse also served as the microfluidics group leader at Battelle's spin-off company, Velocys, where he coordinated reactive flow modeling activities and led several experimental programs for developing chemical micro-channel reactor technology. His current research includes development of a generalized dynamics equation solver for nanoparticle evolution and the application of biological markers for flow measurement and visualization.

Dr. Ann Miracle is currently involved in research incorporating environmental biomarkers into relevant remediation, monitoring, and risk assessment guidelines; and the environmental exposure of nanomaterials to aquatic organisms. Dr. Miracle leads a team of scientists addressing anthropogenic impacts to phylogenetically diverse periphyton and microbial communities. In previous employment with the U.S. EPA, Dr. Miracle led a team of scientists in linkages of exposure and effects using 'omics technologies in small fish models as part of that agency's Computational Toxicology Initiative.

Measurement and Control of Human Exposures

Comprehensive Nanoparticle Exposure Assessment at a Workplace

Battelle researchers, working with manufacturers, designed approaches to assess nanoparticle exposures during product manufacturing and application to determine the potential for health risks. To eliminate the confounding effects of natural background concentrations of nanoparticles, Battelle developed the capability to simulate manufacturing processes in a controlled environment. This enables accurate characterization of exposures through real-time measurement of particle concentrations and sample collection for determination of size-class distribution, number, and particle physicochemistry. These capabilities combined with our unique simulation capabilities, including particle physics and lung dosimetry, reduce the uncertainty in assessing exposure and determining human risk during the production and manufacturing processes.

Measurement of Smoke Particle Distribution in Exhaled Breath

Battelle is among the first to establish methods to measure the fine and ultrafine particle size distribution and particle concentration (N/cm^3) in the exhaled breath of active smokers. Exhaled breath measurements were taken using a particle counting/collection instrument, an Electrical Low Pressure Impactor (Dekati, Ltd., Finland), which uses a 12-stage cascade impactor to provide real-time size classification and collection of particulate matter in the size range from 7 nm to 10 μm . Figure 2 shows a portion of the real-time readout of the breath exhalations from individual puffs from a smoker while smoking a conventional cigarette and the resulting particle

size distribution. Two striking features of these plots are the rapid decrease observed in particle concentration to near-baseline levels within about 30 seconds following each puff, and the preponderance of ultrafine particles in the distribution. The particle distribution plot indicates that the number of particles corresponding to the lowest measurable cutpoint, 7 nm, is greater than that measured for the next five larger cutpoints, ranging from 27 – 259 nm. Given the complex dynamics associated with particle deposition in the lung, this ultrafine particle dominance has potential health implications.

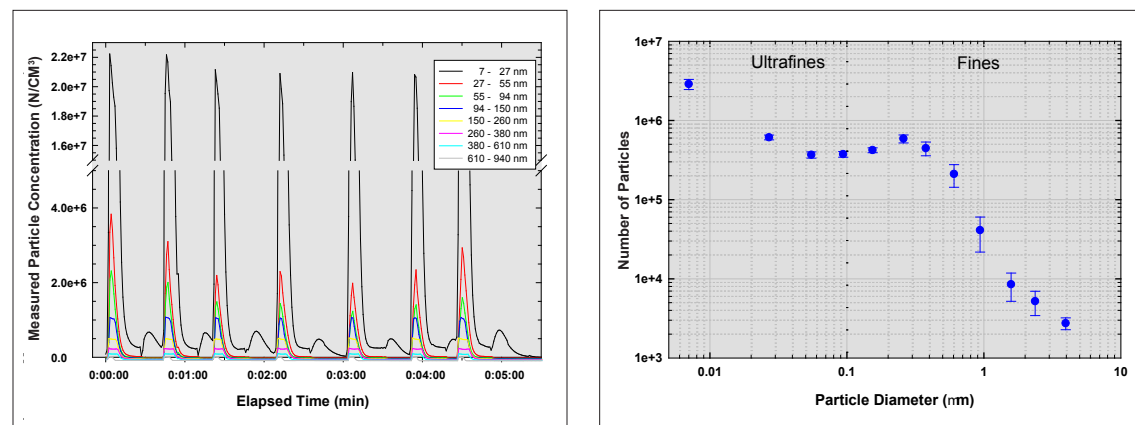


Figure 2. Particle distributions in exhaled breath of smoker after each cigarette puff taken (left figure); particle size distribution from four groups of four machine-smoked cigarettes (right figure)

Respirator Performance Evaluation Using Nanoparticles

NIOSH-approved particulate respirators are routinely used in the workplace to protect against a variety of airborne particulate contaminants. Limited data are available regarding their performance against nano-sized aerosols produced in nanotechnology occupational settings. Battelle performed a study for the U.S. Army Edgewood Chemical and Biological Center and for the NIOSH National Personal Protection Technology Laboratory to assess the filtration efficiency performance of selected N95 and P100 particulate respirator filters over the range of 20 to 1000 nm, as shown in Figure 3. The challenge aerosol was either a polydisperse salt (sodium chloride) or oil (dioctyl phthalate) aerosol depending on the filter rating. Battelle also performed work to characterize the effect of nanoparticle loading on filtration performance. Battelle use both a Scanning Mobility Particle Sizer (TSI, Inc.) and Wide-Range Particle Spectrometer (MSP Corp.) to characterize the size distribution and concentration of nano-sized aerosols. This work was presented at the 2006 American Industrial Hygiene Conference.

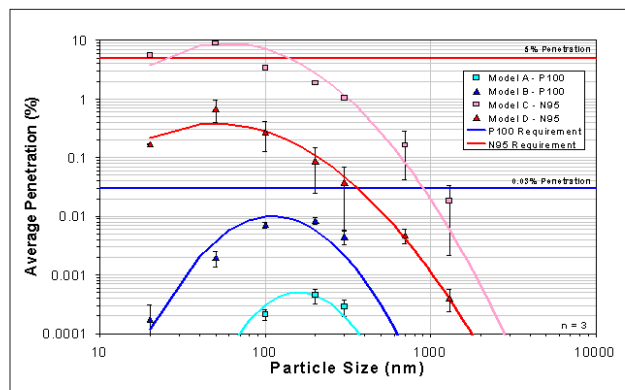


Figure 3. Respirator filter efficiency

Featured Staff

Dr. Sydney Gordon is a leader in the field of human exposure and has played a prominent role in the design, implementation, management, and technical direction of a number of multimedia, multi-pathway, multi-pollutant exposure studies. Major projects included an exposure study aimed at understanding the disease risk associated with the exposure of nonsmokers to sidestream smoke, the Children's Total Exposure to Persistent Pesticides Study, the Agricultural Health Study/Pesticide Exposure Study in Iowa, and the characterization of dermal and inhalation exposure to the fuel additive MTBE. He is co-author of one book and author or co-author of more than 130 journal articles, conference presentations, book chapters, and reports.

Mr. Aaron Richardson has more than eight years' experience on numerous research projects related to the design and evaluation of filter systems for respiratory protection. These studies required significant laboratory effort to generate and analyze vapor and aerosol challenge atmospheres including inert aerosols, bioaerosols, and vapors used in human subjects fit testing and/or mannequin testing. The research required operation of aerosol and vapor collection, sensing, and quantification equipment, including the TSI PortaCount, laser aerosol spectrometers, photometers, TSI Aerosizer, API Aerosizer, and Scanning Mobility Particle Sizer for nanoparticle research, and various methods of bioaerosol generation and sampling.



Measurement and Analysis of Nanomaterials

Chemical Identification and Characterization/Environmental Analysis of Nanomaterials

Battelle is uniquely equipped with a variety of instrumentation used for the chemical identification and characterization of nanomaterials. Our instrumentation and facilities include:

- ELPI
- MOUDI
- Electron and Scanning Probe Microscopy
- Scanning Mobility Particle Sizer
- Wide-Range Particle Spectrometer
- Climet Real-Time Particle Counters
- Aerosol Mass and Raman Spectrometry
- Photo Electron and Auger Electron Spectroscopy
- ICP-MS
- Mist, Aerosol, and Environmental Chambers

Room Air Cleaner Performance Evaluation Using Nanoparticles

Battelle has been actively involved in research related to the potential health implications of aerosols, including those of nanoparticles. In one study for the U.S. EPA's National Homeland Security Research Center (NHSRC), Battelle evaluated the performance of selected air cleaner technologies for safe building applications. A systematic evaluation was completed of the single-pass filtration efficiency for two room air cleaners subjected to particles having a broad spectrum of size distributions.

The study was performed using aerosol particles with diameters as small as 30 nm, which were characterized using a Scanning Mobility Particle Sizer (SMPS) capable of detecting particles down to 20 nm. The air cleaners tested included a filter-based unit and an electrostatic precipitator (ESP); both units were tested using particle size and airflow rate as the test variables. Some of the study results are illustrated in the following graphs in Figure 4.

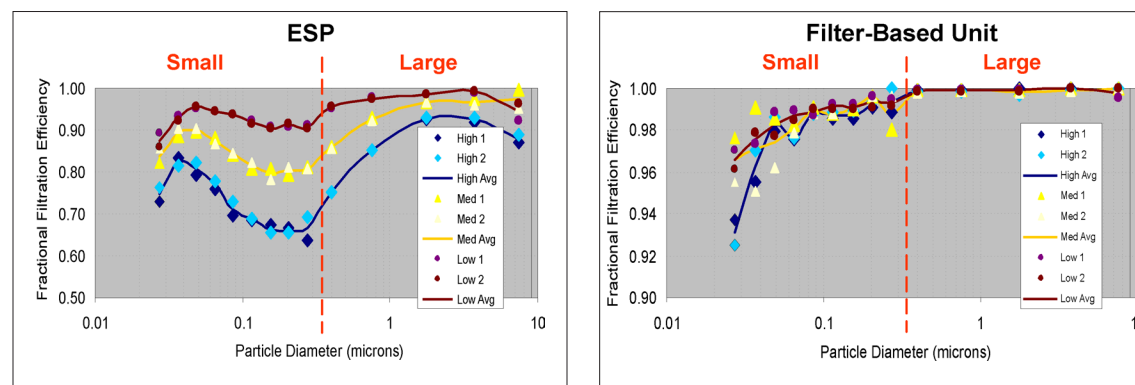


Figure 4. Particle filtration efficiency for two types of air cleaners

Verification of Ambient Fine Particulate Monitors and Personal Cascade Impactor Samplers Through the Environmental Technology Verification (ETV) Program

The U.S. EPA's Environmental Technology Verification (ETV) Program evaluates the performance of innovative environmental technologies. Battelle operates the ETV Advanced Monitoring Systems Center (since 1997), thus is well-poised to verify technologies that could be used to detect, characterize, or quantify nanomaterials. Battelle conducted verification tests of the following technologies applicable to the nanotechnology area:

Personal Cascade Impactor Samplers(PCIS):

The Sioutas PCIS, operating in conjunction with the Leland Legacy® pump, is designed to separate and collect airborne particulate matter in specific aerodynamic diameter size, ranges. The PCIS allows chemical characterization of particulate matter according to particle size which is significant because smaller particles penetrate deep into the lung alveoli and may pose greater health risks. PCIS performance was evaluated during a short-term (10-15 minute) sampling of a test aerosol (KCl) generated in a large chamber (17.3 m³), and a long-term (48 hour) sampling of ambient air metals.

During these tests, chemical and gravimetric comparisons of the PCIS's sampling efficiency were made to more well-known "reference" personal and fixed-site air samplers that were co-located with the PCIS.

Ambient Fine Particulate Monitors: This verification test provided quantitative performance data on 13 continuous fine particle monitors including an electrical low pressure impactor (ELPI) under a range of realistic operating conditions. To meet this objective, field testing was conducted in two phases in geographically distinct regions of the U.S. during different seasons of the year. The first phase of field testing was conducted at the ambient air monitoring station on the Department of Energy's National Energy Technology Laboratory campus in Pittsburgh, Penn., during the fall. The second phase of testing was performed at the California Air Resources Board's Ambient Air Monitoring station in Fresno, Calif., during the winter. Specific performance characteristics verified in this test included inter-unit precision, accuracy and correlation relative

to time-integrated reference methods, effect of meteorological conditions, influence of precursor gases, and short-term monitoring capabilities.

Complete reports are available at <http://www.epa.gov/etv/verifiedtechnologies.html>.

Featured Staff

Dr. Don Baer, Lead Scientist for Interfacial Chemistry at Battelle's Environmental Molecular Sciences Laboratory, is internationally known for the application of surface analysis methods to understand the roles of surface impurities or contaminants on the chemical reactivity and mechanical properties of minerals and other materials. Current research activities include study of the reaction properties and environmental variability of nanoparticles, and synthesis and properties of oxide nanostructures. Dr. Baer specializes in the use of surface sensitive techniques to study surface and interphase reactions and material surface chemistry, and his recent research involves atomic force to examine and create nanoscale features on surfaces. His interest in nanoscience and nanotechnology extends to the characterization and reactivity of nanoparticles and encouraging interactions between Battelle laboratories and other research organizations. Dr. Baer has served as deputy manager of Battelle-managed PNNL's Nanoscience and Nanotechnology Initiative, as Co-Director of the Joint Institute for Nanoscience involving PNNL and the University of Washington, and as the PNNL coordinator for a series of Nanoscience and Nanotechnology courses offered at PNNL. He is currently the Chairman of ASTM Committee E42 on Surface Analysis, and he is preparing a guide for the application of surface analysis methods to nanostructured materials for ISO TC201 SC5.

Mr. Kent Hofacre has led studies to model and predict performance of individual and collective systems focusing on aerosol filtration and gas adsorption, and has led major field sampling efforts related to contaminant transport (vapors and aerosols) both indoors and outdoors. Mr. Hofacre has extensive laboratory and analytical experience regarding various inert aerosol and biological aerosol generation/classification techniques, as well as significant experience regarding generation and analysis of vapor challenges in controlled environmental conditions.

Ms. Amy Dindal is the Program Manager for Battelle's Environmental Technology Verification Program Advanced Monitoring Systems Center. She is responsible for technical oversight and project management for verification tests of air, water, and soil environmental monitoring technologies, including those related to nanoparticles and nanomaterials. Ms. Dindal is the author or co-author of more than 90 peer-reviewed verification reports. She also jointly holds a U.S. patent for an air-monitoring sorbent technology. Ms. Dindal received her Project Management Professional certification in 2006.



Environmental Benefits of Nanotechnology Through Technology Applications

Nano-Based Biosensors

Battelle scientists have discovered a way to increase the sensitivity of test strips that will enable creation of a portable biosensor that can quickly distinguish individuals who have been exposed to chemical or nerve agents from those who have not. Biomarkers, or a change in the proteins that announces something is wrong, exist for every disease. At Pacific Northwest National Laboratory (PNNL), the Battelle team is creating a nanoparticle “label” that can increase the ability of a sensor to detect and interpret the message of biomarkers. The researchers are working with an electrochemical immunoassay approach. This involves using the antibody of a specific disease—a protein produced in response to an invading bacterium or other foreign substance—to attract the biomarker. Labeling a second antibody with a nanoparticle amplifies the biomarker’s signal. The increased level of sensitivity will allow detectors to be very precise in identifying the concentration of biomarkers in biological samples.

Nanoscale Iron Injection for Groundwater Treatment at Launch Complex 34

Battelle supported NASA and the U.S. EPA Superfund Innovative Technology Evaluation (SITE) Program in designing and testing injection of an innovative nanotechnology solution developed by NASA to treat chlorinated solvents, such as trichloroethylene (TCE), in soil and groundwater. Handling of the nanoparticles can be a challenge because of their high reactivity and potential for dust formation. Potential for passivation of the nanoparticles before their contact with the groundwater contaminants is another challenge. Dense non-aqueous-phase liquid (DNAPL) contaminants, such as TCE and perchloroethylene, have been discovered in groundwater at thousands of sites across the country because they have been used for common commercial applications, such as dry cleaning and metal finishing.

These solvents were used by NASA to clean rocket engines before mounting them on rockets as part of the lunar program in the 1960s. These solvents were released to the ground after use and have accumulated in the soil and groundwater beneath the Engineering Support

Building at NASA’s Launch Complex 34 (Figure 5). Being denser than water, the solvent penetrated the water table and is smeared across the thickness of the surficial aquifer down to a clay layer at 40 ft below ground surface. NASA has found that nanoscale zero-valent iron emulsified with vegetable oil reacts with TCE and other solvents and converts it to nontoxic byproducts. This project was the first field test of the concept. Nanoscale iron has a high surface area that enhances the strong reductive capacity of elemental iron. The nanoscale iron was injected into the aquifer beneath the building; and within weeks, TCE levels declined substantially.



Figure 5. Engineering Support Building at NASA’s Launch Complex 34, where an innovative nanotechnology solution was implemented to treat chlorinated solvents in groundwater

Evaluation of the Effectiveness and Cost of Nanoscale Iron Treatments at Four Department of Defense Sites

Battelle provided expert consulting and troubleshooting services to the Navy in evaluating the effectiveness and cost of nanoscale iron applications at four sites. Short-term and long-term field application data were evaluated to identify challenges, determine causes, and recommend alternative methods of application. Nanoscale zero-valent iron is used for groundwater treatment because it acts as a strong reducing agent capable of destroying many common groundwater contaminants, such as chlorinated solvents. However, the high reactivity that makes this product attractive can pose challenges in storing, handling, and delivering this reagent to the subsurface. Different injection methods vary in their ability to distribute the nanoparticles in the aquifer and retain their reactive properties. Based on the experience at these four sites, Battelle implemented intensive training to Navy personnel in six commands on the proper design, storage, handling, and optimization of nanoscale iron use.

Featured Staff

Dr. Yuehe Lin's main research areas are the development of miniaturized analytical systems based on a lab-on-a-chip concept for environmental and biomedical monitoring, such as the development of integrated capillary electrophoresis/electrospray mass spectrometry for characterization of proteins and DNA, and microfluidics/electrochemical sensors for detection of metals, toxic organic compounds, and biomolecules. His other research area includes the synthesis of nanostructured materials for sensor development, catalysis, and separation applications. Dr. Lin is the author or co-author of more than 100 peer-reviewed publications, 16 project reports, nine patents (five issued, four pending), and 60 presentations (16 invited). Two of his publications in carbon nanotubes/biosensors have been among the top 10 most cited papers in chemistry based on a recent citation analysis by the Institute for Scientific Information (ISI) and were featured in ISI's newsletter, *Science Watch* (July–August issue, 2004).

Mr. Arun Gavaskar manages projects related to soil and groundwater remediation, sediment management, storm water and wastewater treatment, and pollution prevention. He has wide experience with a variety of pollutants, such as chlorinated solvents and dense non-aqueous phase liquid (DNAPL), heavy metals, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), dioxins, and pesticides. Mr. Gavaskar chaired the prestigious International Conference on Remediation of Chlorinated and Recalcitrant Compounds in Monterey, Calif., in 2000, 2002, and 2004. He has given invited presentations on environmental technologies at several international forums.

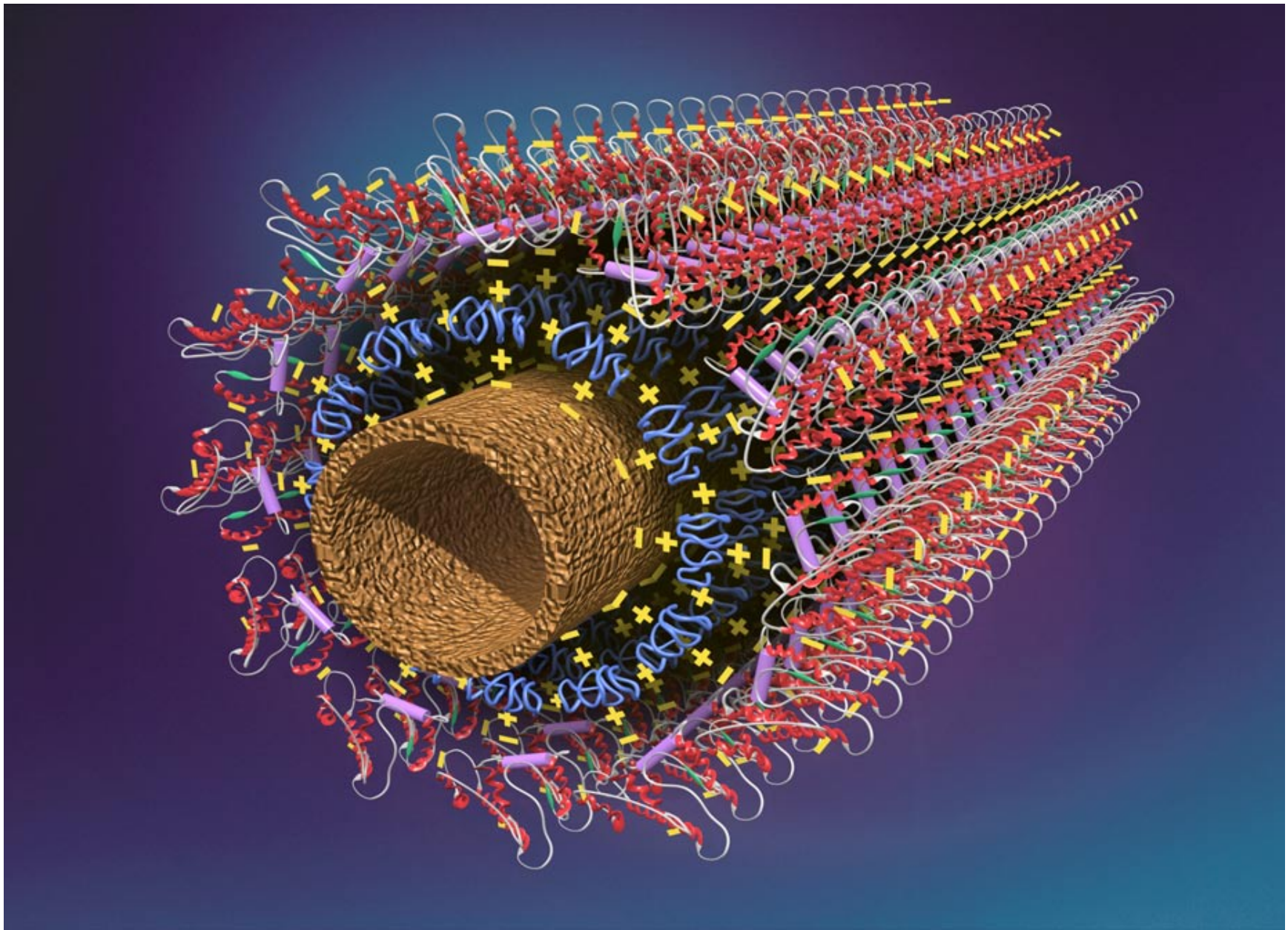
Responsible Development

Battelle Nanotechnology Innovation Alliance

The Battelle Nanotechnology Innovation Alliance leverages capabilities across Battelle and in collaboration with universities, industry, and other organizations to support the National Nanotechnology Initiative (NNI) and respond to industrial challenges and opportunities that will advance nanoscience and commercialize new products. Through the Alliance, clients have access to health and safety and materials science experts who can help industry be proactive in designing safe nanotechnologies and materials. Toward those ends, the *Battelle Nanotechnology Innovation Alliance* includes:

- The *Center for Functional Nanomaterials* at Brookhaven National Laboratory;
- National Renewable Energy Laboratory;
- The *Center for Nanophase Materials Sciences* at Oak Ridge National Laboratory;
- The *ESML Interfacial and Nanoscale Science Facility* at the Pacific Northwest National Laboratory;
- Lawrence Livermore National Laboratory;
- Idaho National Laboratory; and
- Battelle's R&D labs in Columbus, Ohio.

The Alliance is succeeding on many fronts. For example, the Alliance supported The Ohio State University (OSU), the University of Akron, and the University of Dayton to win a \$22.5 million grant from the State of Ohio to establish the "Center for Multifunctional Polymer Nanomaterials and Devices." Another collaboration with OSU resulted in an \$11.5 million Ohio Department of Development grant to establish the Ohio BioProducts Innovation Center (OBIC) which is co-located at OSU and Battelle. This Innovation Center is focused on collaborating with industrial members, national labs, and other universities to create differentiated material solutions using renewable resources like corn and soybeans. Battelle also worked with the University of Toledo, OSU, Bowling Green State University, the national labs managed or co-managed by Battelle, and several companies to assist in the establishment of the \$18.6-million Ohio Wright Center for Photovoltaics Innovation and Commercialization, which includes the responsible development of nanostructured materials for solar energy applications.



Policy and Planning

Connecticut Nanotechnology Strategic Framework

The Connecticut Office for Workforce Competitiveness, as part of its recent statutory charge to advance Knowledge Economy policies for the state, commissioned Battelle to assess Connecticut's relative position in nanotechnology and develop a strategic approach to advance the state's nanotechnology resources and assets. A detailed industry assessment of nanotechnology impacts on Connecticut's economy was completed, along with a strategic framework involving seven key action steps for enhancing university-industry collaborations and advancing a competitive technology infrastructure for nanotechnology development. Since completion of the framework, Battelle has assisted Connecticut in:

- The implementation of nanotechnology initiatives;
- Helping to secure ongoing state support and designing educational programs;
- A nanotechnology innovation grant for industry;
- A nanotechnology industry-university collaboration initiative to match key university capacities to industry needs and support fellowships of graduate students and post docs;
- Advancing the concept of a major shared-use center for nanoscale sciences.

Mid-Atlantic Nanotechnology Alliance (MANA)

Working with the states of New Jersey, Pennsylvania, and Delaware, Battelle's Technology Partnership Practice identified the tri-state (Southeastern PA, Delaware, and Southern NJ) industry base in nanotechnology, its university and other research institutions' nanotechnology capacities and research activities and competencies, and identified core nanotechnology focus areas around which the newly established Alliance can focus business higher education government efforts. The work included benchmarking, market assessments, and analysis of quantitative data sources. Battelle also prepared an implementation approach for MANA in its next round of EDA funding, including the need and concept for a regional nanotechnology alliance, which is being advanced for future funding.

Massachusetts Technology Roadmap and Strategic Alliances Study

Battelle assessed the growing expertise in nanotechnology found across Massachusetts industry and universities, including leading programs at Harvard, UMass Amherst, MIT, Northeastern and UMass Lowell, and identified specific areas for future development and strategic alliance development. Two specific

nanotechnology initiatives were developed as part of this core competency study, including a nanoscale device fabrication facilities network and a smart materials technology incubator. For each opportunity, Battelle analyzed the context, economic benefits, federal funding prospects, potential for industry linkages, competitive positioning of Massachusetts, examples of leading initiatives in other states, and recommendations on specific activities and state support required.

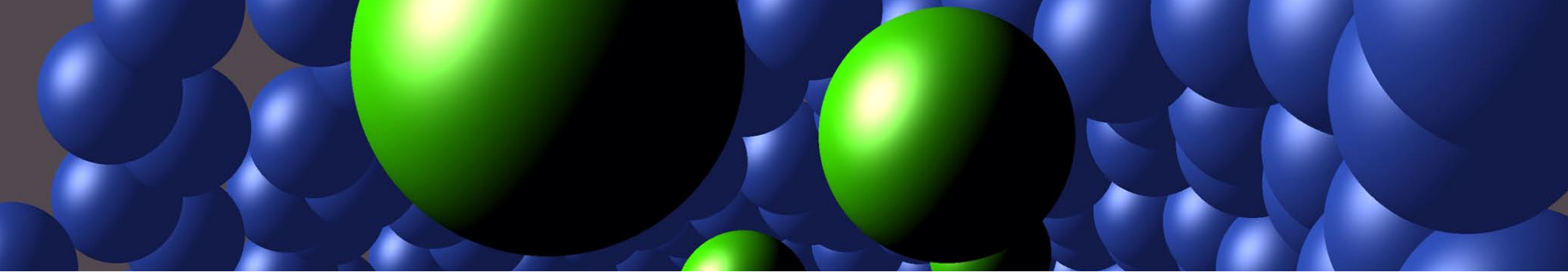
Northeast Ohio Polymer Strategic Opportunity Roadmap

Battelle identified the implications of nanotechnology on the development of new nano-based polymer additives and nanocomposites and the role of nanotechnology on the development of new functional polymers (e.g., photonic and conductive polymers). Recommendations were made to focus additional resources and develop centers of excellence in these specific areas.

Featured Staff

Mr. Mitch Horowitz is Director of Strategy for Battelle's Technology Partnership Practice. At Battelle, Mitch has led numerous efforts involving nanotechnology development, including efforts for the Mid-Atlantic Nanotechnology Alliance and the states of Connecticut and Massachusetts. In the early 1990s, Mr. Horowitz served as Technology Advisor for the State of Maryland's economic development agency. In his efforts in Maryland, Mr. Horowitz had the unique experience of preparing Maryland's widely acclaimed biotechnology strategy as a consultant to the State, and then took on the responsibility for implementing that strategy as Technology Advisor. Mr. Horowitz holds a Master's in Public Policy from the Kennedy School of Government at Harvard University and a B.S. from Cornell University.

Mr. Martin Grueber served as the principal consultant for Battelle's efforts in developing a polymer strategic opportunity roadmap for Northeast Ohio and served as the technical lead in assessing nanotechnology core competencies for Battelle's work in Connecticut and with the Mid-Atlantic Nanotechnology Alliance, which included cluster analysis of nanotechnology-related patents and federal grant awards. Prior to joining Battelle, Mr. Grueber served as Deputy Director of the Rhode Island Economic Policy Council, where he managed the Slater Technology Development Fund, and was co-author of the 1997 Rhode Island Strategic Economic Plan. He also worked as a Manager at the Michigan Manufacturing Technology Center, where he co-authored strategic and operating plans of one of the largest NIST/MEP programs, and was a project manager and principal analyst for industry and regional analysis contract research activities for the Industrial Technology Institute.



Battelle is the world's largest non-profit independent research and development organization, with more than 20,000 employees in more than 130 locations worldwide, including seven national laboratories Battelle manages or co-manages for the U.S. Department of Energy and the U.S. Department of Homeland Security. Headquartered in Columbus, Ohio, Battelle conducts \$4 billion in R&D annually through contract research, laboratory management, and technology commercialization.

Battelle provides innovative solutions to some of the world's most important problems including global climate change, sustainable energy technologies, high-performance materials, next-generation health-care diagnostics and therapeutics, and advanced security solutions for people, infrastructure, and the nation. Battelle has a long history of developing successful commercial products in collaboration with its clients, ranging from products to fight diabetes, cancer, and heart disease to the development of the office copier machine (Xerox). As a non-profit charitable trust with an eye toward the future, Battelle actively supports and promotes science and math education.

Battelle
The Business of Innovation

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