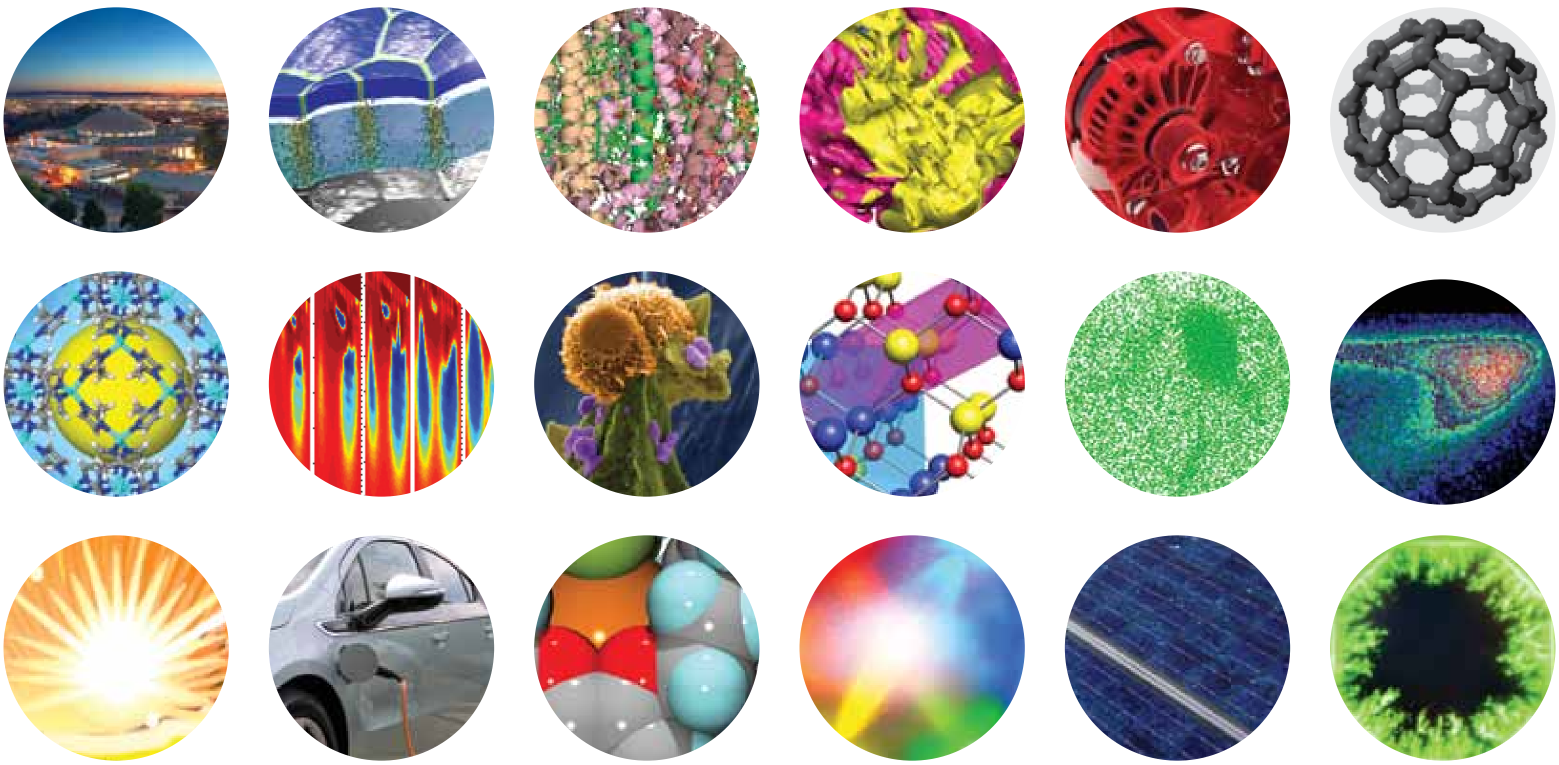
Science Serving the Nation

The Impact of Basic Research

Basic Energy Sciences



U.S. DEPARTMENT OF ENERGY | Office of Science

Science Serving the Nation

The Impact of Basic Research

Basic Energy Sciences

BASIC ENERGY SCIENCES ENERGY ENVIRONMENT SECURITY

MATERIALS SCIENCES ENGINEERING CHEMICAL GEOSCIENCES BIOSCIENCES

RESEARCH UNDERSTAND PREDICT CONTROL MATTER ENERGY

This document highlights the breadth of the scientific programs and the impact of this research in commerce and in advancing scientific frontiers. To look in more detail at our research portfolio and see how we manage our programs, consult our BES 2011 Summary Report, available at http://science.energy.gov/~/media/bes/pdf/reports/files/bes2011sr_rpt.pdf. Additional information about the impact of BES research can be found on our website at http://science.energy.gov/bes/. New highlights showcasing the benefits of BES programs are frequently posted to the web as they arise.

Our user facility brochure (http://science.energy.gov/~/media/bes/suf/pdf/BES_Facilities.pdf) contains additional information on all of the BES national scientific user facilities.

Energy technologies, environmental technologies, and national security all depend on the progress of basic science research. By understanding, predicting, and ultimately controlling matter and energy at the level of electrons, atoms, and molecules, scientists have the capacity to transform the technologies we use in everyday life.

From Fundamental Science to Energy Technology

Basic Energy Sciences (BES) supports the science that is the foundation for new technologies essential to the U.S. Department of Energy (DOE) missions in energy, environment, and national security. We are one of the Nation's leading sponsors of fundamental research across broad areas of materials sciences and engineering, chemical sciences, geosciences, and biosciences.

Our research portfolio includes individual and small group research, as well as 46 multidisciplinary Energy Frontier Research Centers and two Energy Innovation Hubs. Of course, BES science is not the only contributor to technology advances—the DOE technology offices and small business innovative research program, along with industry, have played key roles in the development of research and technology demonstrations critical to nearly all of these successes.

Demonstrated Excellence in Science

Part of DOE's Office of Science, BES has demonstrated a long history of excellence in science. Nine Nobel Prizes, recognizing science's ultimate leaders, have been awarded to BES-supported scientists and for research at BES user facilities since 1986. Our high-profile scientists are recipients of many individual international awards and recognitions, including over 175 members of the National Academies of Science and Engineering. Many more of our scientists have achieved leading reputations in their fields, honored as fellows of scientific and professional societies.

In addition to the Nobel-prize-winning work, BES has enabled significant scientific advances such as the development of synchrotron x-ray light sources; superior plastics via better catalysts; new types of superconductors; lithium batteries; plant genome sequencing; and new types of microscopy.

Scientific User Facilities for the Nation

Responsible for their planning, construction, and operation, BES is the steward for many of the Nation's most sophisticated scientific user facilities. These facilities are open to researchers from all disciplines at no charge through a peer review process. At these world-class facilities, physicists, materials scientists, chemists, environmental scientists, and biologists can correlate the structure of materials from atoms to biomolecules with their physical, chemical, or biological properties. Our x-ray light sources, neutron scattering facilities, nanoscale science research centers, and electron-beam microcharacterization centers provide exceptional instrumentation for advancing science in basic and applied energy-related disciplines.

These powerful scientific tools yield critical insights into electronic, atomic, and molecular configurations, often at distances as small as a few atoms and time scales as short as those of molecular vibrations—the realm of the ultrasmall and ultrafast. In sum, they make experimental studies possible that cannot be conducted in ordinary laboratories, in the process facilitating leading-edge research that benefits from merging ideas and techniques from different disciplines. Our newest user facility, the Linac Coherent Light Source, is a world leader in ultrafast science—illuminating processes that happen on ultrafast time scales, from chemical reactions to understanding molecular motion.

BES user facilities hosted over 14,000 researchers in fiscal year 2011 from academia, national laboratories, and industry. Private-sector users of these advanced scientific capabilities came from more than 300 companies, ranging from Fortune 500 companies to small businesses. The impact of this industrial user community is significant—including the discovery of new cancer treatment drugs and new, improved battery technology for electric cars and consumer electronics.

Nobel Prizes

Since 1986

1986 *in Chemistry*

For the dynamics of chemical elementary processes including a new type of experiment that revealed the evolution of a chemical reaction, step by step.

1987 *in Chemistry*

For the development and use of molecules with structure-specific interactions of high selectivity, including the incorporation of guest molecules into hollow host molecules.

1994 *in Physics*

For pioneering neutron scattering techniques, now widely used around the world to understand materials structure, chemistry, and properties.

1995 *in Chemistry*

For pioneering contributions to understanding the formation and decomposition of ozone in the atmosphere, including the "hole" in the ozone layer at the poles.

1996 *in Chemistry*

For discovery of a novel form of carbon consisting of 60 carbon atoms with a soccer ball-like structure, the first of a vast new class of carbon-structures with novel properties.

1997 *in Chemistry*

For revealing how enzymes synthesize adenosine triphosphate (ATP), the molecule that stores energy to power cellular processes.

2003 *in Physics*

For advances in the theory of superconductors, materials that can conduct electricity with no energy losses, thus opening new avenues to energy technologies.

2005 *in Chemistry*

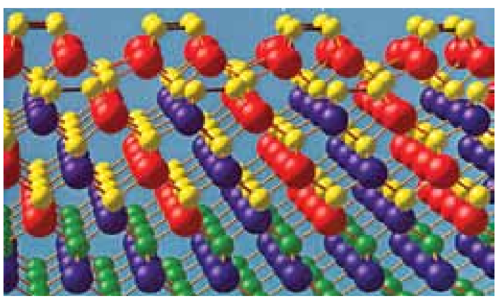
For devising new methods of organic synthesis, now used in the chemical, food processing, and biotechnology industries.

2009 *in Chemistry*

For mapping (with BES synchrotron light sources) the structure and inner workings of the ribosome, the cell's machinery for churning out proteins from the genetic code.

Better Ways to Tap the Sun's Energy

A Multilayer Path to Efficient Solar Cells

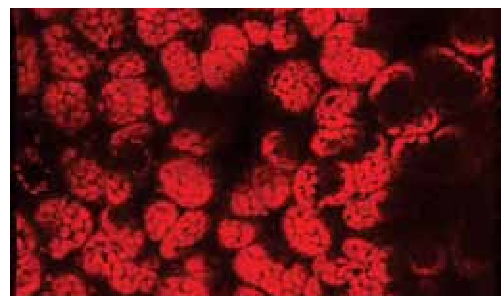


More energy from the sun strikes the Earth in one hour than is consumed by humans on the planet in a year, making solar energy our most potent clean energy resource. Yet, performance and cost have prevented solar cells from being tapped as a major energy source. Fundamental research to better understand how solar photons are converted to electronic energy at the nanoscale, and how that energy is ultimately converted into electrical current, is required for the science-based design of next-generation solar cells. In one example, scientists designed each layer in a multilayered solar cell to absorb a different portion of the solar spectrum, allowing more sunlight to be converted into electricity, i.e., increasing the cell's efficiency. Materials with this type of "designed" solar absorption are now in use in commercial solar cells. Continued research on ways to enhance photovoltaic efficiency could launch the next generation of solar cells.

Microspheres for Low-Cost Thin-Film Solar Cells

One way to reduce the cost of solar cells is to use less material, but the penalty is less light absorbed. Fundamental research on light trapping and absorption is paying off with new strategies for production of cost effective and highly efficient solar cells made from thin films. For example, to capture more of the incident light, optical coatings on these cells now include microspheres to scatter and reflect sunlight through the cell many times, so that virtually all the light is used. Adding these tiny particles to an array of silicon nanowires increases absorption to 90% of the sunlight, while significantly reducing the amount of silicon far below that used for conventional photovoltaic cells. Other cost reductions are coming from basic research including how to make thin-film devices reproducibly and with high quality. Successfully combining these approaches has now yielded a new generation of flexible, organic-based solar cells.

Mimicking Nature to Turn Sunlight into Fuels



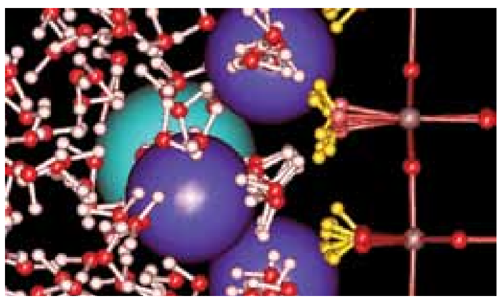
Plants, algae, and some bacteria use solar energy to convert water and carbon dioxide by means of photosynthesis into chemical energy for cellular processes like growth and reproduction. Nature has had billions of years to modify and refine this remarkable process, optimizing the capture of sunlight while avoiding damage from excess light. Synergistic research in biology, chemistry, physics, and materials science are showing us how photosynthesis works and thereby spawning innovative strategies for artificial photosynthesis based on non-living "molecular machines" that generate fuels directly from sunlight, water, and carbon dioxide. Ultrafast "snapshots" of photosynthesis in action have generated fresh insights into structures and mechanisms that scientists can use to mimic nature in the service of direct solar fuel systems based on environmentally sustainable and cost-effective materials. No direct solar-to-fuels industry currently exists, so success in this area would mean a transformative change in renewable-fuels technology, with profound economic and environmental benefits.

Efficient Approaches to Power the Future

Superconductivity Science on the Grid

Superconductors, materials that can conduct electricity with 100% efficiency, have always offered the tantalizing prospect of transforming electrical technology, if only refrigerating them to near absolute zero didn't cost so much. So-called high-temperature superconductors, complex ceramics that become superconducting at liquid nitrogen temperature (still cold at -196 °C or -321 °F, but far warmer than previously possible), changed all that. Since their discovery in the 1980s, much research has focused on understanding how they work. BES research aimed at evaluating their structure, chemistry, and electronic properties yield insights into growth mechanisms and current flow in these materials. This research has led to new technological approaches for manufacturing superconducting wires made up of multiple layers of different materials. Today, industry has deployed cables wound from the wires in several demonstration projects on the electric power grid, and the technology has spread to projects around the world.

From Basic Science to Nuclear Energy



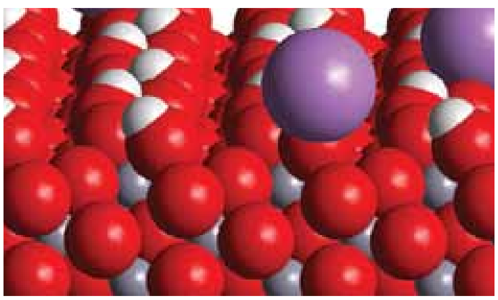
Because the potential consequences of accidents at nuclear power plants are so severe, safety is a prime concern. One aspect is the integrity of the reactor materials. The extreme heat, pressure, and radiation inside nuclear reactors are challenges for existing materials. Fundamental research is helping scientists discover how to make new materials that can better withstand this environment. Understanding what causes cracks to form in materials exposed to radiation fields has provided a basis for evaluating the condition of reactor structural components, information needed to determine whether the reactor can safely operate for longer times. Spent reactor fuels pose problems of their own. Fundamental separations science—understanding how to separate and capture the atomic elements in materials—has led to novel ways to preferentially capture the different components found in spent fuels, thereby protecting the environment and preserving national security.

Nanoscience's Mega Impact in Better Batteries

In the realm of the ultrasmall, nanoscience is all about materials and phenomena at length scales around the size of tens of atoms, far smaller than the microsized width of a human hair. Basic and applied battery research has shown that the introduction of nanosized particles will enhance the conductivity and improve the design of the interface where the battery's electrode meets its electrolyte. This innovative design gives batteries longer life, more stability, and enhanced power for improved performance in today's vehicles, power tools, and other consumer applications. To further advance the science, theorists have worked out calculations to predict new materials that will exhibit even better performance. As a complement to advanced modeling, advanced experimental techniques developed at BES user facilities are being used to monitor dynamic chemical changes during battery cell operation and measure the electronic properties of new electrode materials.

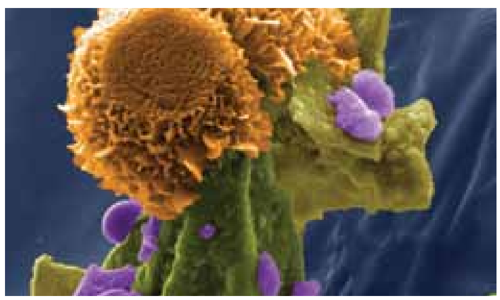
Innovative Seeds for Clean Energy Technologies

New Catalysts for Future Electric Vehicles



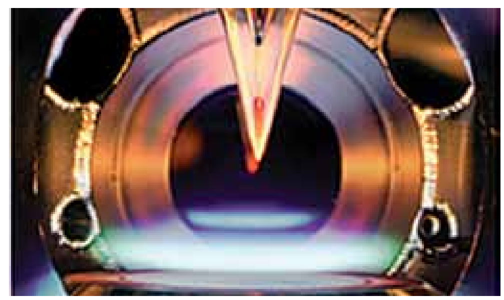
Catalysts, materials that accelerate and direct the outcomes of chemical reactions, are ubiquitous in the chemical, pharmaceutical, and petroleum industries and also widely used in transportation (the well-known catalytic converter in exhaust systems). Combining directed experiments and theory, researchers are transforming current knowledge about how catalysts behave, including those based on nanosized metal particles. For example, fundamental studies on tailored, mixed-metal particles have paved the way to synthesizing a novel catalyst that minimizes the use of precious platinum metal while showing excellent reactivity and longevity. This catalyst is slated for use in next-generation fuel-cell powered electric cars. Additional understanding of structure-function relationships resulted in another new class of catalysts that are now used in the exhaust-after-treatments of efficient, lean-burn diesel engines.

Keeping Carbon out of the Atmosphere



Fossil fuel burning power plants have a problem: They emit carbon dioxide, a climate-changing greenhouse gas, into the atmosphere. One way to reduce atmospheric carbon dioxide is to capture the gas before it is emitted from power plants and then store it permanently underground. Thanks to basic geosciences research, computational tools now exist that use underground images made by electromagnetic waves to reveal geological formations that could store captured carbon, and find new fossil fuel reserves. Analyzing suitable storage sites involves processes taking place over enormous length and time scales, from reactions of individual molecules with minerals in a billionth of a second to flow and transport in subsurface formations extending hundreds of kilometers and taking hundreds of years. At the same time, new materials are being developed that more efficiently capture carbon dioxide from mixed gas streams, as well as materials that use bio-inspired approaches to sequester the carbon into a stable mineral form suitable for storage.

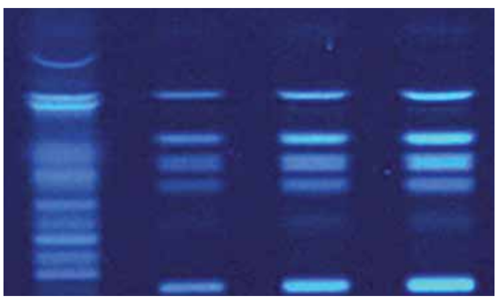
Science for Clean and Efficient Combustion



Internal combustion and diesel engines run mostly on petroleum fuels, but they don't have to. Ethanol, a non-petroleum-based renewable fuel is already one alternative, and more are likely in the future. In anticipation of new, 21st century fuels and new engines to burn them, chemical researchers are applying fundamental combustion science to address the significant need for predictive simulation of what happens when complex fuels are burned in modern engines. Basic combustion research takes advantage of advances in multi-scale computational tools, validated by sophisticated laser diagnostics of actual reactions in realistic situations, to accurately model the interaction of turbulent engine flow involving combustion chemistry that can have as many as 10,000 distinct chemical reactions involving 1000 different compounds. These kinds of studies lay the foundation for science-based engine design that reduces the time and cost of engine development, while yielding higher fuel efficiency and cleaner operation.

Converting New Insights into New Technologies

Tools for Scientific Progress and Pioneering Technologies



Innovative instrumentation for characterizing materials and processes drives advances in science and development of transformative technologies. Some examples show how: Fundamental research in laser analysis contributed to the development of an industrial technology for determining the elements contained in diverse objects, from children's toys to contaminated soils with reduced time, cost, and waste generated as compared to traditional analysis procedures. Similar research in mass spectrometry, a widely used technique for chemical analysis, has extended the range of detectable species to more complex molecules, such as the pollutants in engine exhaust. In addition, BES synchrotron user facilities have standardized procedures for structural determination of bio-molecules, structures used by companies in developing new pharmaceuticals. Finally, our ability to manipulate matter at the nanoscale has led to new materials with impacts ranging from improved DNA analysis to MRI machines that are light-weight, energy efficient, portable, and accessible.

From the Laboratory to the Manufacturing Factory Floor

Discovering new materials is not enough. Understanding how to make materials with the properties one wants is critical to the manufacturing of useful products that take advantage of the discovery. Atomic defects such as impurities provide a case in point. More efficient solid-state lighting based on light-emitting diodes or LEDs and an improved design for the LED manufacturing process are based on theoretical models of the material and the role of harmful defects. Atomic-level understanding of the role of additives to metals has led to a new class of alloys that can withstand high temperature and therefore can be used in furnaces for manufacturing. Additives have also yielded new aluminum alloys for lighter weight vehicles. More generally, synthesis research has paved the way for new U.S.-based manufacturing of high quality powders and ways to use "superplastic" forming—stretching metals to form specific shapes—to greatly simplify the production of light-weight components for vehicles and other weight-critical applications.

Scientific Discovery for a Cleaner Environment

Chemical pollution has severe environmental consequences. Two ways to reduce pollution include using non-toxic materials from the start and designing effective ways to clean up what has already been released. For example, understanding how to design better materials has led to the discovery of lead-free solder. This solder is now used worldwide to tie together the millions of individual parts in electronics, while eliminating the toxic lead in standard solders from going into landfills. Where the environment has already been contaminated, remediating groundwater near landfills or waste dumps depends on a better understanding of how waste materials can bind with chemicals in the soil and water. Today, water containing industrial contaminants is being purified with specially designed, highly porous silica (the material that makes up sand), treated with special binders that trap the contaminants. Similarly, new molecules that bind radioactive contaminants are in use to treat the decades-old wastes from historic nuclear weapons research.

Enabling Solutions Through Science

Whether it's making better solar cells or creating more efficient combustion, whether it's cleaning contaminated soil or discovering new materials, or whether it's mimicking nature's own processes or inventing entirely new ones, basic science drives the technology that provides solutions for society's needs. The DOE Office of Science, Basic Energy Sciences enables science for solutions through its broad support of leading-edge research at hundreds of institutions across the Nation, through single investigator grants, small-group research, and larger multidisciplinary teams.

Through careful strategic planning, in close cooperation with the broader scientific community, BES has defined a research agenda, embodied in a series of scientific grand challenges, designed to meet the energy needs of society by harnessing the insights and capabilities of a new era of science. In this new era, we design, discover, and synthesize new materials and molecular assemblies through atomic scale control; probe and control photon, phonon, neutron, electron, and ion interactions with matter; perform multi-scale modeling that bridges multiple length and time scales; and use the collective efforts of condensed matter and materials physicists, chemists, biologists, molecular engineers, applied mathematicians, and computer scientists.

By considering the broad energy needs of society, and focusing research on the discoveries that will help meet these needs, BES builds the foundational science essential to achieving our most important technological goals. BES-supported research brings truly transformational scientific understanding for addressing our Nation's challenges in energy, the environment, and national security.

BASIC ENERGY SCIENCES ENERGY ENVIRONMENT SECURITY

MATERIALS SCIENCES ENGINEERING CHEMICAL GEOSCIENCES BIOSCIENCES

RESEARCH UNDERSTAND PREDICT CONTROL MATTER ENERGY

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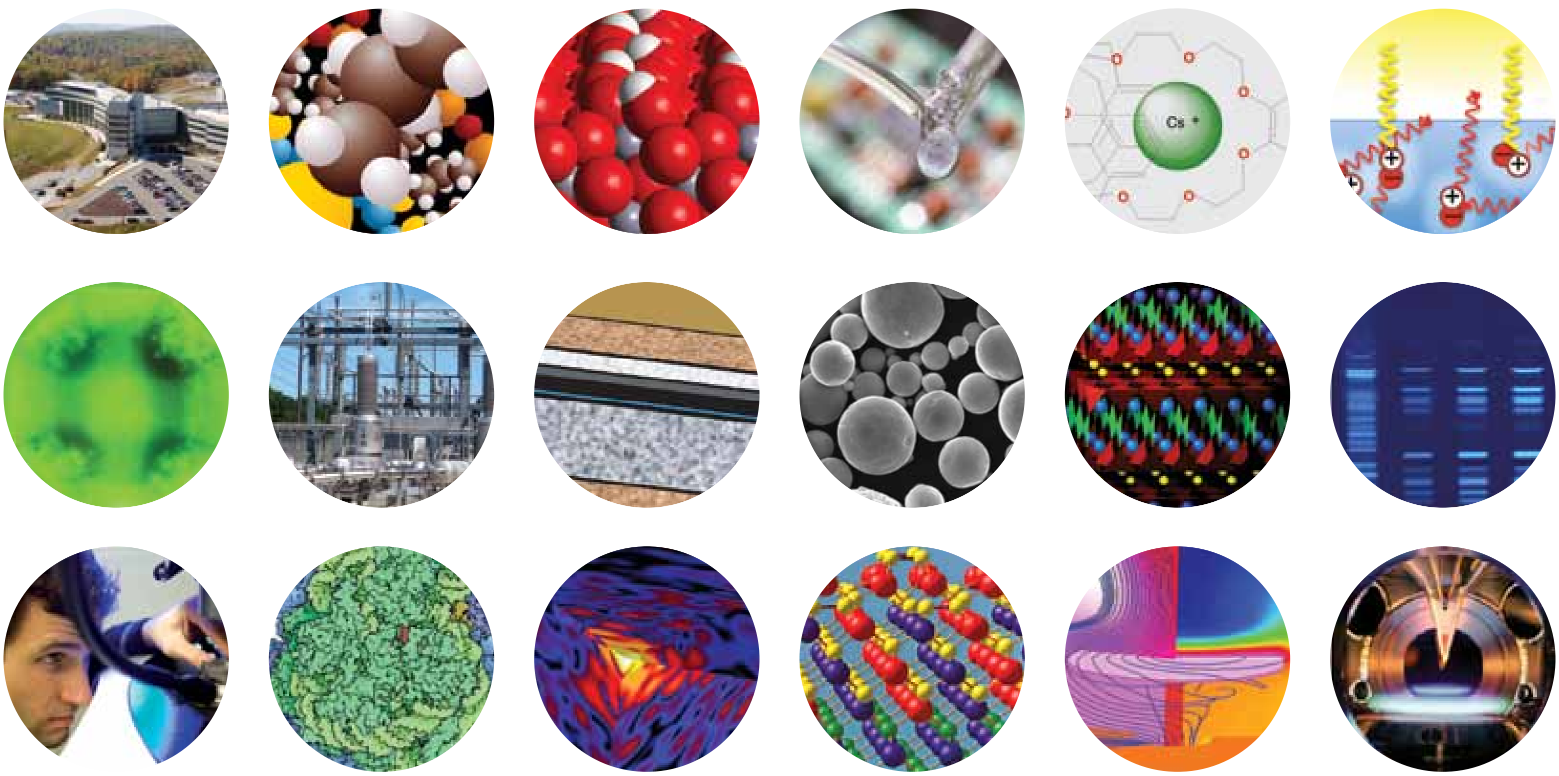

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