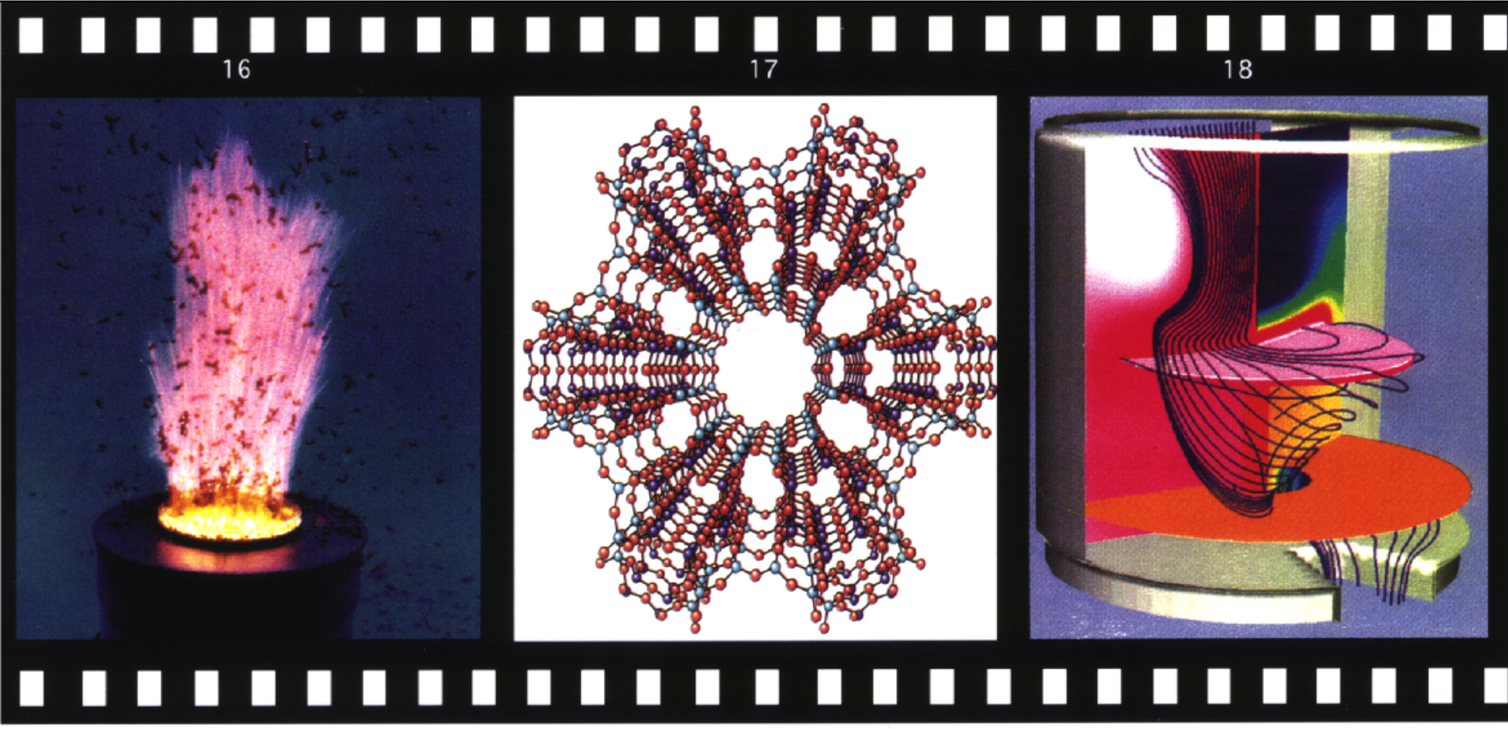


# Basic Energy Sciences

## Serving the Present, Shaping the Future

M • ABB • ABC Laboratories • Accurate Automation • ACE Glass Company • Advanced Acoustic Concepts • Advanced Ceramics • Advanced Composite Materials •
dvanced Micro Device • Advanced Refractory Technologies • Advanced Research Development • AGIP • Air Products and Chemicals • ALCAN Aluminum • ALCOA •
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Applicable Electronics • Applied Materials • ARCO Chemical • Armco • ASTeX • Astronautics Corporation • Atlas Wireline Services • AT&T • Avery-Dennison • Babcock &
Vilcox • Baker Chemical • Basic Aircraft Research • BELLCORE • Bethlehem Steel • Bioanalytical Systems • BioCryst Pharmaceuticals • BioSym • Boeing • BP America •
Bristol-Meyers Squibb • Bruker Instruments • Cabot Corporation • Calgon Vestal Labs • Carborundum • Cargill Incorporated • Carpenter Corporation • Caterpillar • Cement
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Hoskins Manufacturing • Hughes Aircraft Products • IKU • Illinois Superconductor •
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JEOL USA • JNOC • Jobin-Yvon • John Deere • Johnson Manufacturing • Kairos • Kennametal • Keramount • Kinetic Systems • Kodak • Komag Corporation • Komwave •
Kopin Corporation • Lachat Instruments • Lake Shore Cryotronics • Lam Research • Lambda Research • Lambda Technologies • Lamson and Sessions • Lederle Laboratory
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Union Carbide • United Technologies • Universal Energy Systems • Unocal • UOP • Upjohn • USCAR • Valenite Corporation • Vapex Environmental Technologies •
W. R. Grace • Western Atlas International • Westinghouse Electric • X-Ray Instrumentation Associates • Xerox • Xsirius Superconductivity

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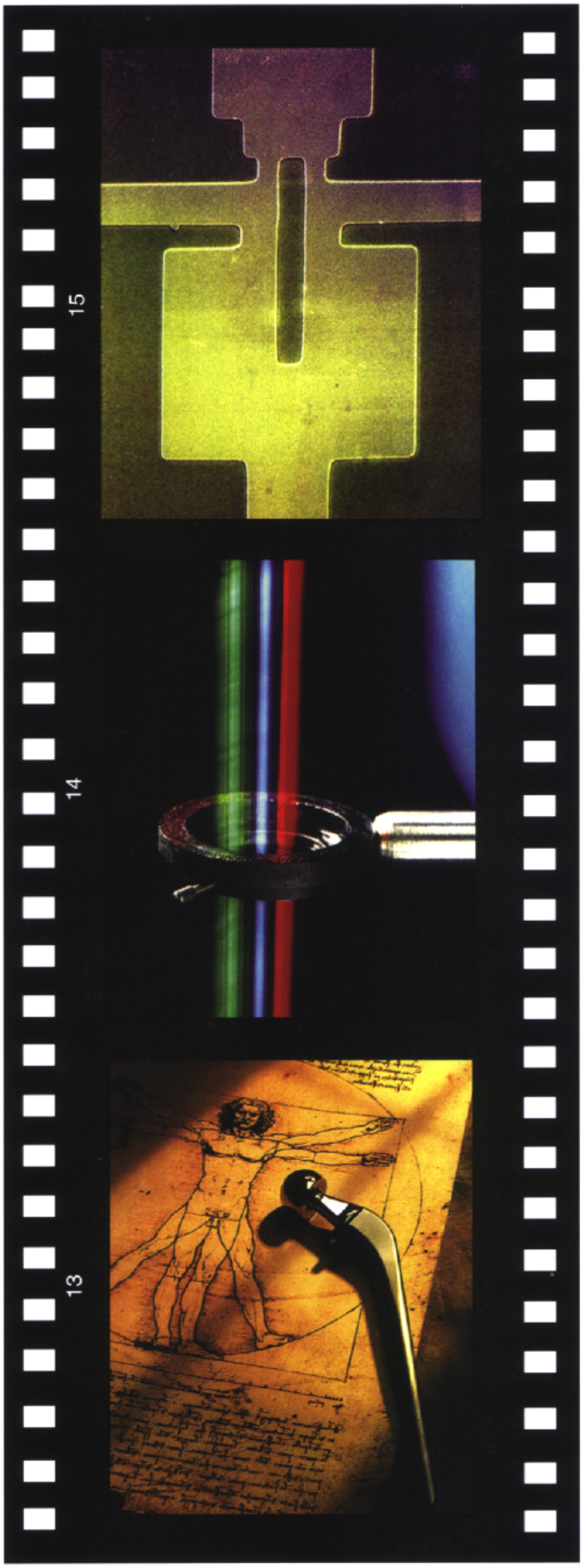



# Contents



# Contributors

**Many people contributed to this document. First, of course, are the many dedicated researchers whose work is highlighted in this brochure. In addition, Manfred Leiser and Christie Ashton, Division of Materials Sciences, began the project and shepherded it to completion; Linda Horton, Oak Ridge National Laboratory, provided invaluable help through her experience as a manager of basic research and as a contributor to many of the examples; and Jane Cross and Art Robinson, Lawrence Berkeley National Laboratory, applied their technical writing skills to make this brochure not only a reality, but also useful to a broad audience. Tim Elledge and Lisa Wright provided assistance in producing initial drafts of the brochure. John Smith provided invaluable assistance with the computer graphics and photography. His expertise brought unfailing high quality to the figures in this brochure. Finally, Phyllis Teague provided the comprehensive technical editing and expertise in layout design that brought the brochure to publication. Thank you.**

# The Office of Basic Energy Sciences

The Office of Basic Energy Sciences (BES) is one of the Nation's foremost sponsors of fundamental research in broad areas of materials sciences, chemical sciences, geosciences, biosciences, and engineering sciences. The BES program underpins the Department of Energy's (DOE's) missions in energy and the environment, advances energy-related science on a broad front, and provides unique national user facilities for the scientific community. Encompassing more than 2,400 researchers in 200 institutions and 17 of the Nation's premier user facilities, the program involves extensive interactions at the interagency, national, and international levels.

BES communicates the essence of its mission in three words — excellence, relevance, and stewardship:

- excellence in basic research
- relevance to the Nation's energy future
- stewardship of the Nation's research performers and the institutions that house them to ensure the stability of essential research communities and premier national user facilities.

Combining and sustaining these principles are both the challenge and the vision of the office. Further, taken together, these principles underpin the value to the Nation of basic research.

## The Value of Basic Research: An Assessment

Those who conduct, manage, and sustain basic research see its impact and believe in its value. From time to time, however, it is useful to independently assess its value to those outside of the scientific research community. To do so, Dr. Martha A. Krebs, Director of the DOE's Office of Energy Research, asked the Basic Energy Sciences Advisory Committee (BESAC) to assess, without restraint, "how the Nation has received a return on the taxpayer's investment in the Basic Energy Sciences program."

To fulfill this charge, BESAC engaged the help of economist John H. Moore of George Mason University* to head a panel to investigate the question. This panel was unique in that a significant number of its members represented the non-scientific community. It contained influential members from industries, other federal agencies, and Congressional staff, as well as leading scientists from the basic research community. The panel reviewed..

- program information presented by the staff of BES
- testimony presented by technical staff from five other federal agencies (the National Science Foundation, the National Institutes of Health, the National Aeronautics and Space Administration, the U.S. Geological Survey, and the Department of Defense)
- results of other studies including two initiated by the panel
- results of the panel members' site visits to nine national laboratories and two universities that conduct a great deal of BES-funded basic research

The panel's efforts culminated with the BESAC report, *Knowledge for the Nation's Future: The Social Value of Basic Energy Sciences*, which concluded that the research supported by BES provides an excellent return on the investment. The report summarizing the

*Current address: Professor John H. Moore, President, Grove City College, 100 Campus Drive, Grove City, PA 16127-2104.

panel's work is available from the Office of Basic Energy Sciences.

## Excellence: Award-Winning Basic Research

Basic research creates the knowledge that underlies and stimulates new technologies. Identifying the best ideas and nurturing the best talent are essential to achieving excellence in a basic research program. To ensure that it funds quality efforts, BES submits each program or project to merit evaluation and peer review. As a result of this constant adherence to the peer review process, BES researchers and their students receive extensive recognition. For example, *within the past decade*, the following BES principal investigators have shared in five Nobel prizes:

- Yuan T. Lee, University of California, Berkeley, for "dynamics of chemical elementary processes" (Nobel Prize in Chemistry, 1986)
- Donald J. Cram, University of California, Los Angeles, for "development of molecules with structurally specific interactions of high specificity" (Nobel Prize in Chemistry, 1987)
- Clifford G. Shull, Massachusetts Institute of Technology, for "pioneering contributions to the development of neutron scattering techniques for studies of condensed matter." (Nobel Prize in Physics, 1994)
- Frank Sherwood Rowland, University of California, Irvine, for "work in atmospheric chemistry, particularly concerning the formation and decomposition of ozone" (Nobel Prize in Chemistry, 1995)
- Richard E. Smalley, Rice University, for "collaborative discovery that carbon could occur in a uniquely beautiful and satisfying structure that engendered an entirely new branch of chemistry" (Nobel Prize in Chemistry, 1996)

One of the hallmarks of the BES program is that its researchers are recognized for their contributions to basic science, applied science, technology development, and R&D integration. BES researchers typically win many of the major prizes and awards in basic science each year, as well as several of the R&D 100 awards.

Over the years, external reviews of BES programs have reached the same conclusions as those of the BESAC panel: the research supported by BES is of high quality, whether it's conducted at the national laboratories, by scientific staff or users at BES user facilities, or by academic researchers.

**Neutron scattering was pioneered at Oak Ridge National Laboratory in the 1950s by Nobel Laureate C. G. Shull (standing) and E. O. Wollan.**

## Relevance: BES and the Nation's Energy Future

BES is uniquely responsible for supporting basic research in the natural sciences that have led to new and improved energy technologies. It supports fundamental research in energy resources, production, conversion, and efficiency, and mitigation of the adverse impacts of energy production and use.

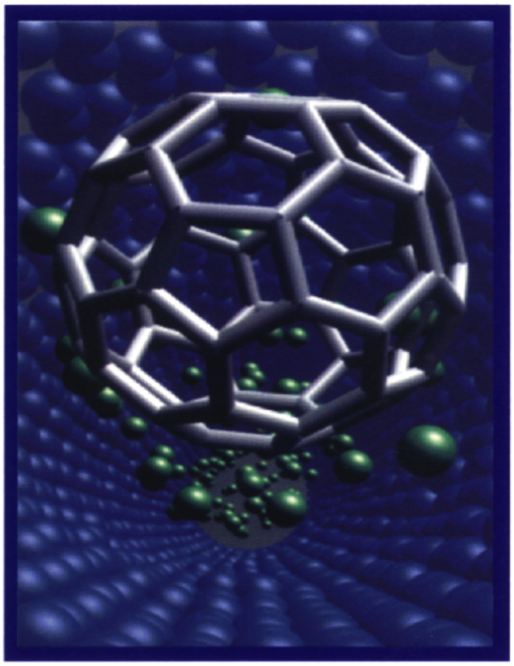
BES also relies heavily on broad input from the scientific community to help define new research directions and to aid the process of integrating basic research with applied research and development activities. For example, BES sponsors or co-sponsors dozens of workshops each year to help define new directions in basic research and to evaluate current technology needs.

To meet the Nation's future energy needs, the best scientific and technological resources *must* be employed together. Through its diversified portfolio of basic research programs and its system of university and laboratory programs, BES promotes interdisciplinary research such as this and also integrates basic science, applied science, and development activities.

The national laboratory system plays a large part in BES's ability to effectively integrate research and development by providing opportunities to co-locate activities at these sites. Approximately one in every three scientists supported by BES at the national laboratories also receives support from at least one of DOE's technology programs. In this way, BES helps guarantee that energy technology development is conducted with the benefit of state-of-the-art scientific knowledge and that basic research programs are focused in areas directly relevant to energy systems.

More importantly, because revolutionary discoveries often transcend the scope of an original scientific inquiry, BES defines the scope of its programs in broader terms than those defined by DOE technology programs or by industry. In fact, important discoveries can *transform* current technologies. Because of this, BES has linked its funded activities with US. industries so that discoveries such as these can rapidly enter the marketplace.

Basic research also precipitates the invention of new scientific instruments. In a number of key industries, for example, instruments that were first developed as tools for laboratory investigation-as a byproduct of the search for new knowledge — have become essential capital goods at the heart of totally new production and technology development.



**Buckminsterfullerenes, co-discovered by Nobel Prize winner Richard E. Smalley, are carbon atoms bound in a soccer ball shape.**

**Nobel Laureate Y. T. Lee's crossed molecular beam experiments revolutionized the fundamental understanding of chemical reactions.**

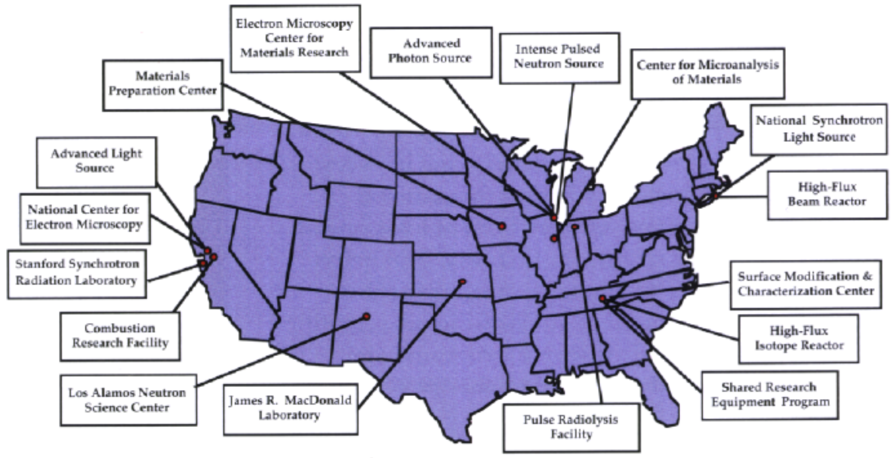
The BESAC report acknowledges the value of BES's strategy for linking basic research with energy technologies and with industry. Given that a deep transformation is happening in the U.S. R&D system, including a shift away from basic research and toward more product-related work, industry is increasingly reliant on fundamental research resources that provide the necessary reservoir of scientific knowledge.

BES's industry R&D strategy is particularly valuable in its heightened focus on research partnerships with outside organizations, especially universities and government laboratories. Industry is relying on R&D at these institutions to maintain the level and diversity of talent and knowledge needed to meet its often unpredictable needs, either in place of, or to supplement, in-house research activities.

To meet these needs, BES designs its programs by means of numerous workshops that involve industry participation and use industrial scientific personnel as reviewers of university and national laboratory research. The value to industry of these collaborations is evident in industry's use of the results of BES research.

Because BES basic research programs are focused in selected scientific areas important to the mission of DOE, many of these programs have achieved outstanding strength in certain disciplines and subdisciplines. For example, BES is the primary funding entity of basic research in many areas of the natural sciences. One such focus is in organometallic chemistry, which is a fundamental research area in chemical sciences that has great importance to catalysis, Indeed, researchers supported by BES won the first 10 awards in organometallic chemistry following the inception of this award in 1985 by the American Chemical Society.

**BES Scientific User Facilities**




**BES research facilities serve over 4500 researchers from universities, industry, and government laboratories each year.**

## Stewardship: Supporting the Nation's Basic Researchers and the Institutions that House Them

Many of the hundreds of technological discoveries that transform our lives and improve our standard of living are the result of federally sponsored research, which has long provided a stable environment for scientific discovery. An important function of the BES program, therefore, is its stewardship of the Nation's basic researchers and the universities and national laboratories that house them.

Nationally, BES is one of the major supporters of fundamental research in the physical sciences. In FY 1994, according to an NSF survey, BES programs comprised...

- 24 percent of the total Federal Government funding for research in physics
- 14 percent in chemistry
- 18 percent in metallurgy and materials
- 11 percent in mechanical engineering

BES also funds programs in other fields (the earth and life sciences) that are directly relevant to DOE concerns and complementary to research supported by other Federal agencies. In fact, in some aspects of these programs, BES is the major source of support.

Furthermore, the report noted, BES-funded research also contributes to the Nation's graduate education and knowledge base. BES research provides continuity and support in the university research system and complements the educational role by funding post-doctoral fellows in the laboratories.

BES is also responsible for planning, constructing, and operating many of the Nation's most sophisticated research facilities. These include high-brightness synchrotron light sources, high-flux neutron sources, electron-beam microcharacterization centers, and specified facilities for materials synthesis, combustion research, and ion beam studies.

The 17 facilities operated by BES, which are unmatched in their breadth of capabilities and numbers of scientific users, have an enormous impact on science and technology. Important research in these facilities has ranged from determining the structure of superconductors and biological molecules to developing wear-resistant prostheses, from characterizing environmental samples at the atomic scale to elucidating geological processes, from producing unique isotopes to developing new medical imaging techniques.

The report also recognized the unique role BES has played through its national scientific user facilities, noting that "in its role of a support for the user facilities BES should be viewed as the steward of a critical national resource." The user facilities supported by BES help enable science that would otherwise be impossible; in fact, the report stated, "an effective national research program could not continue without them. The value of the user facilities flows to the DOE itself, to other Federal agencies, to academia, and to industry..."

## Science Serving the Present and Shaping the Future

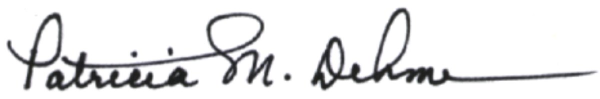
Two earlier publications, *Basic Energy Sciences: Research for the Nation's Energy Future* and *Scientific Research Facilities: A National Resource*, provide an overview of BES and the user facilities supported by BES. These brochures are available from the Office of Basic Energy Sciences.

This brochure focuses on the more than 800 interactions involving BES researchers and industry (BES funds almost no industrial research directly). These collaborations have ranged from informal arrangements among scientists to formal agreements between or among institutions. BES scientists and industrial scientists choose with whom and when to collaborate, each provides their own resources, and each applies the resulting knowledge to their own respective "missions."

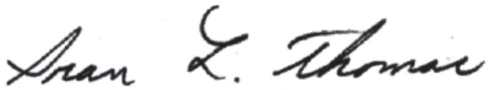
In many cases, especially those involving energy industries, the collaborations just naturally grow out of BES-supported research. Other collaborations, however, occur spontaneously, and some have little to do with DOE's energy mission. This is not surprising, since such unexpected applications are the nature of basic research.

The rest of this brochure describes some of the BES-supported research that has made a significant impact on industry. These stories highlight the relevance and truly exemplify the value of basic research. BES could not tell these stories, however, unless the men and women involved strived to achieve the same excellence, relevance, and stewardship. In many ways. these are their stories, too.

*November 1, 1996*



*Patricia M. Dehmer*
*Associate Director of the Office of Energy Research*
*Office of Basic Energy Sciences*



*Iran L. Thomas*
*Deputy Associate Director of the Office of Energy Research*
*Office of Basic Energy Science*

**The Advanced Photon Source opens new realms of research in the structure of materials.**

# Energy Efficiency

## reducing America's utility bills

**Tests and evaluations by AlliedSignal and Ames Laboratory have shown that making improvements in the processing of the core magnets used in transformers reduces energy losses by up to a factor of 10. Their research suggests that postprocessing improvements, such as surface annealing and laser scribing, could enhance the magnetic properties of the transformer materials, significantly reducing the estimated $1 billion lost each year as a result of inefficiency in these materials.**

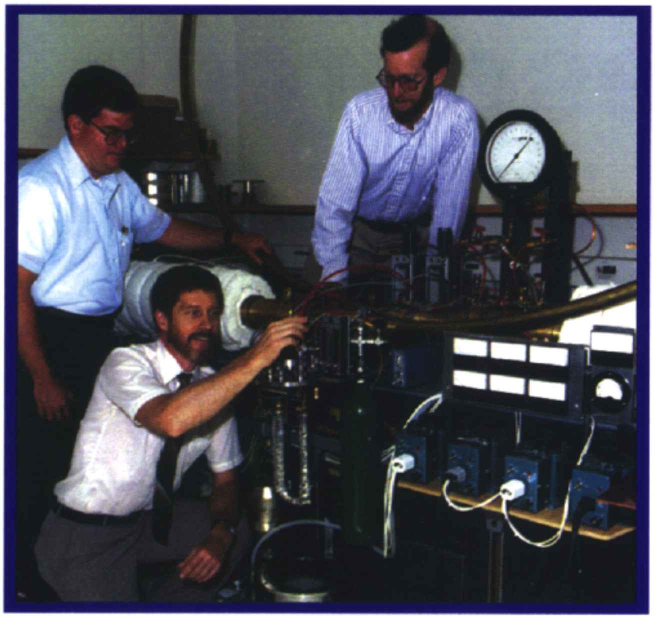
Reducing energy costs and improving energy storage are two ways BES research is helping meet the Nation's goals for increased conservation and more effective energy use. From rechargeable microbatteries to energy-efficient refrigeration, the energy technologies developed and transferred to industry by BES are aimed at meeting the public's demand for dependable, low-cost energy.

Many utility companies have sought the expertise of researchers to improve the efficiency and performance of their operations. One BES-industry project that investigated energy losses from transformers found a way to reduce those energy losses by a factor of 10. This one discovery could significantly reduce the estimated $1 billion lost each year as a result of energy inefficiencies in transformer materials.

BES researchers are also working with industry to develop environmentally safe industrial burners that can maintain flame stability, yet emit low levels of nitrogen oxides (precursors to acid rain and contributors to the formation of smog). The results have been used in the design of a burner for metals processing that reduces typical nitrogen oxides emissions by over 90 percent.

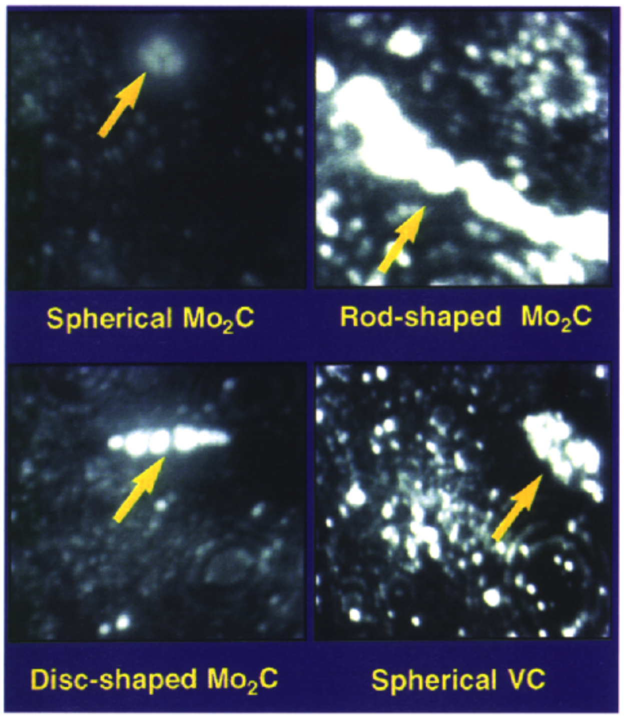
New designs and enhanced performance may one day soon make nuclear power a more attractive energy option. Current research is looking to design longer lasting materials that can better withstand the neutron environment of a nuclear reactor. Researchers are also working on perfecting a technique that detects stress-corrosion cracks in the early stages by "listening" for the sounds that the cracks make as they grow. These efforts, in turn, will help reduce component failure in materials used in electric power generation.

Ultralow-temperature thermoacoustic refrigeration devices have been developed as a result of BES research in thermodynamics and acoustics. These new refrigerators, which cool without moving parts, are more reliable, longer lasting, and environmentally safer (no chlorofluorocarbons) than conventional refrigerators.



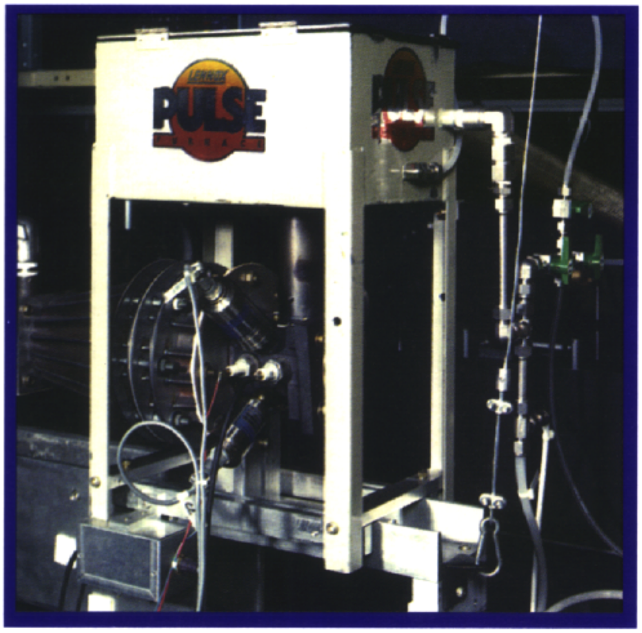
# Thermoacoustic Power

(left) Research in thermodynamics and acoustics at Los Alamos National Laboratory has led the way for several companies, including Cryenco and Ford Motor Company, to develop power and refrigeration systems that are simpler and longer lasting than conventional units. Researchers dubbed the first cryogenic thermoacoustic device, developed by Los Alamos in collaboration with the National Institute of Standards and Technology, a "Coolahoop" because the brass portion of the acoustic resonator that extends upward resembles a "hula-hoop."




# Pulse Combustion

(below) Experiments at Sandia National Laboratories' Combustion Research Facility help companies such as Lennox Industries improve and expand their product lines. Recent work has demonstrated that pulse combustors such as the one shown here can achieve ultralow emission levels without postcombustion cleanup technologies.

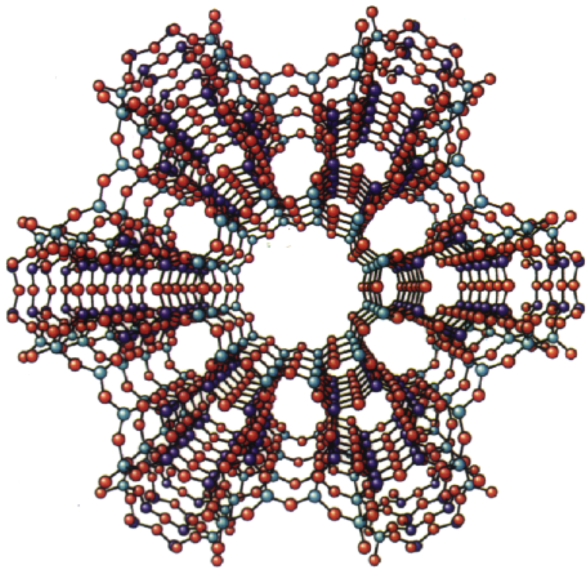



# Visualizing Defects

(above) Several companies have drawn on the expertise of Pacific Northwest National Laboratory and Oak Ridge National Laboratory to study microstructural changes in materials used in nuclear power systems. Currently, collaborative projects are under way with Westinghouse Bettis Laboratories and the Electric Power Research Institute. These efforts use microscopy techniques to investigate defects caused by exposure to radiation of materials used in the pressure vessel and structure of reactors.

# Energy Resources

**contributing to an abundant, secure energy supply**



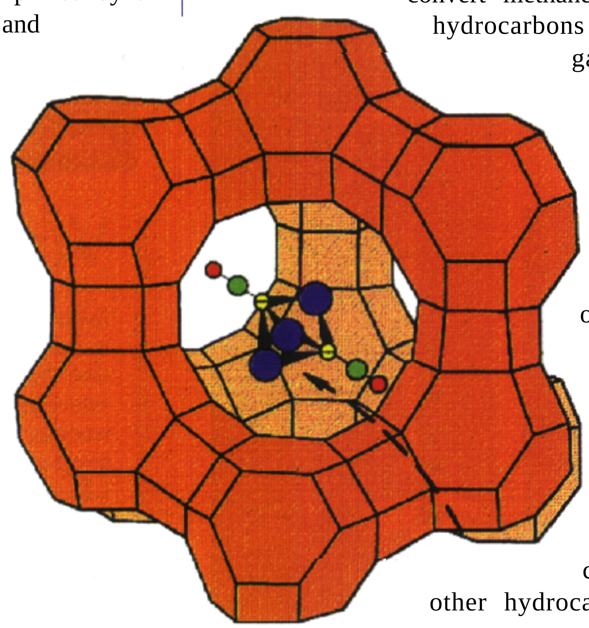
**Our nation's largest petroleum and chemical companies (Amoco, Chevron, Dow Chemical, Mobil, and others) are using the BES synchrotron light sources and neutron sources to gather information about the three-dimensional structure of the molecules they use in their manufacturing processes. For example, knowledge about the local environment of specific atoms — such as in this zeolite catalyst-could lead to more efficient petroleum refining.**

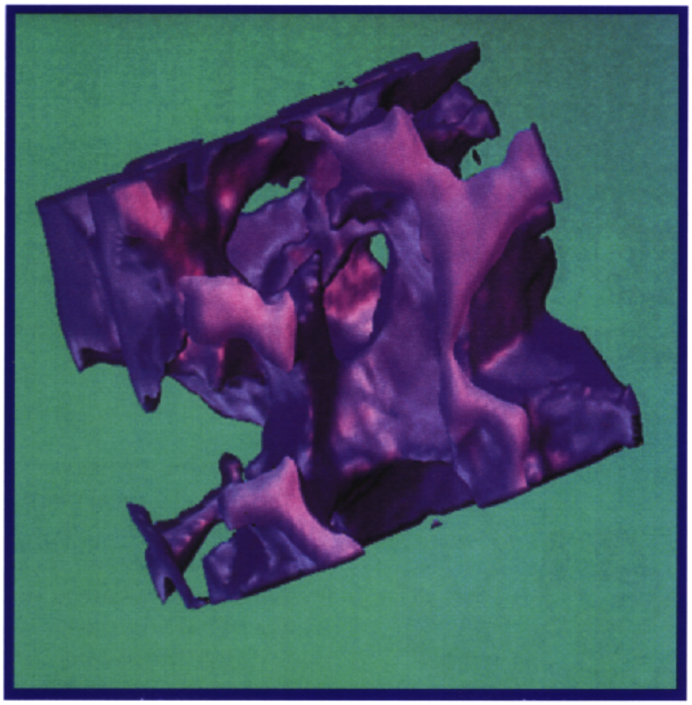
Massive industrial R&D efforts have focused on developing advanced techniques for producing energy and finding more productive ways to tap our existing supplies. BES scientists are also playing an active role in many of these research areas, such as renewable energy research — exemplified by a solar cell with a record high efficiency — and investigations of fossil fuels.

BES researchers are working with petroleum companies to locate new fossil fuel reserves and predict oil reservoir output. However, much of the oil in already-known fields cannot be recovered by conventional techniques. In an effort to make oil recovery operations more effective — thereby enhancing the stewardship of our natural resources — BES is studying the structure of porous rock found in oil fields and developing computer models for the flow of oil through channels in the rock. The petroleum industry, in turn, is using this information to develop additives that enhance the recovery process.

In an effort to make the refining process more efficient, BES researchers are also collaborating with major petroleum producers to develop improved catalysts. For example, BES-funded synchrotron light sources and neutron sources provide industry with the means to determine the structure and fundamental properties of catalyst materials, the precise roles catalysts play in reactions, and how they might be favorably modified.

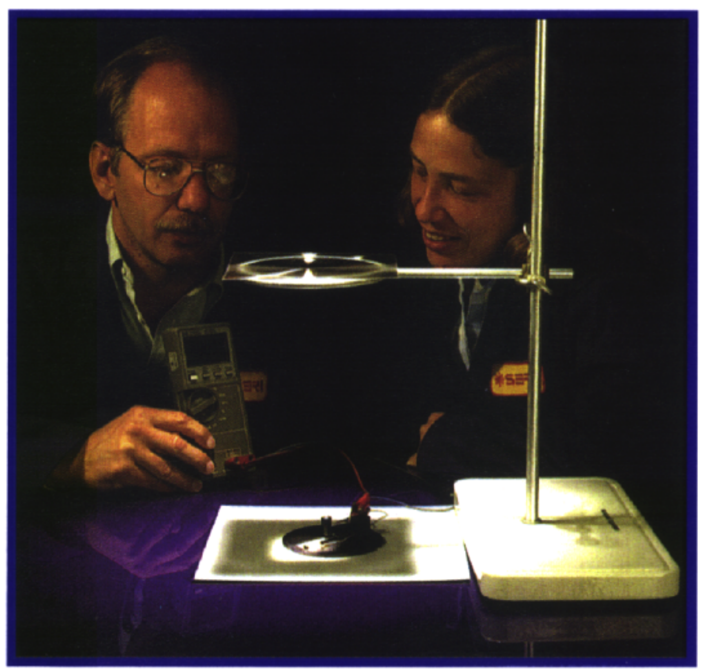
Developing practical industrial processes for converting refining waste products, such as methane gas or petroleum coke, to commercially viable fuels and chemicals is also a compelling economic and environmental goal. For example, a process that could convert methane directly to liquid hydrocarbons or condensable gaseous compounds would overcome the current barriers to using the vast quantities of methane that are presently either capped at the well or wastefully flared into the atmosphere. A BES/industry team has already made significant progress in developing catalysts that have an ability to convert methane to other hydrocarbons.





# Fluid Flow in Rock

This X-ray micrograph, made at the National Synchrotron Light Source at Brookhaven National Laboratory, shows the structure and connectivity of porosity in Fontainebleau sandstone found in oil fields. Scientists at Exxon Research and Engineering Company, Schlumberger-Doll, Princeton Materials, and National Institute of Standards and Technology are collaborating to improve their understanding of oil flow within the sandstone and, by extension, the efficiency of managing oil field reservoirs.



# Catalytic Clusters

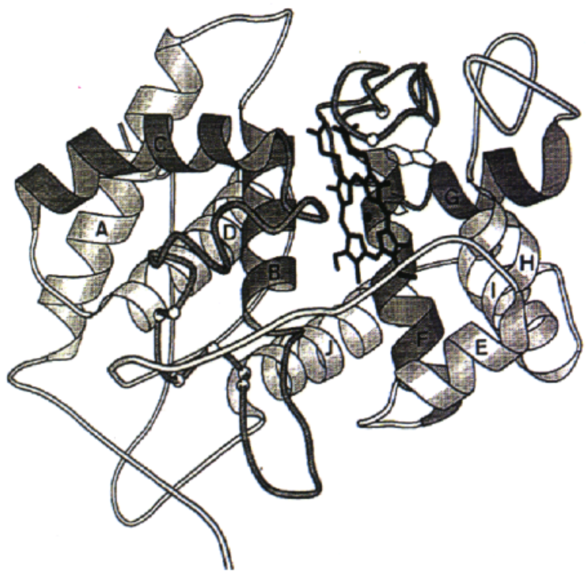
(left page) Scientists at Argonne National Laboratory and Amoco Corporation are working on a more efficient process to convert natural gas into other, more valuable hydrocarbons such as motor fuels. The catalysts that drive the process are made by modifying large-pore, molecular-sieve materials to produce catalytically active molecular clusters (like the one shown in the diagram on the left page). Different varieties of the catalysts can be created by simply changing the pore size of the sieve and adjusting the encapsulated cluster.

# Solar Energy

The National Renewable Energy Laboratory recently set a world record for efficiency in a solar cell: 29.5 percent! This achievement has led to a number of collaborations with companies, such as Spectrolab, Spire, and Kopin, who are interested in learning how to fabricate and commercialize this state-of-the-art device.

# Environmental Technology

## effective, less–expensive remediation therapies



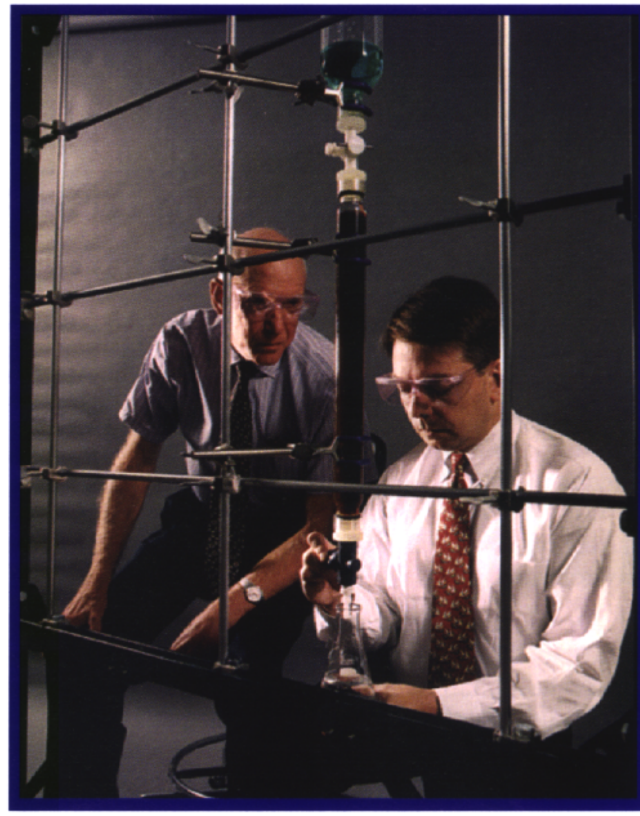

**Enzymol International called on the expertise and resources of Lawrence Berkeley National Laboratory scientists to help define and refine the properties of a peroxidase enzyme the company developed. This enzyme holds great promise for commercial use because it degrades highly toxic waste chemicals such as PCBs (polycholorobiphenyls) and CPCs (chlorophenols). These persistent and damaging chemicals have, so far, resisted detoxification.**

As we become increasingly aware of how our activities alter the world's ecosystems, we realize how urgently we need technologies that help identify, characterize, monitor, control, and remediate pollutants. Transforming the results of basic research into commercially attractive strategies for remediation is particularly important — and it is an objective BES scientists and industry are working on together.

One of the most daunting tasks is cleaning up wastes generated by nuclear weapons production. In such cases, choosing the most effective remediation strategy demands a clear understanding of the waste site and of the nature of the contamination. In these ways, BES researchers have helped industry develop several accurate, rapid environmental technologies for locating, measuring, and recovering highly toxic materials, such as uranium and strontium.

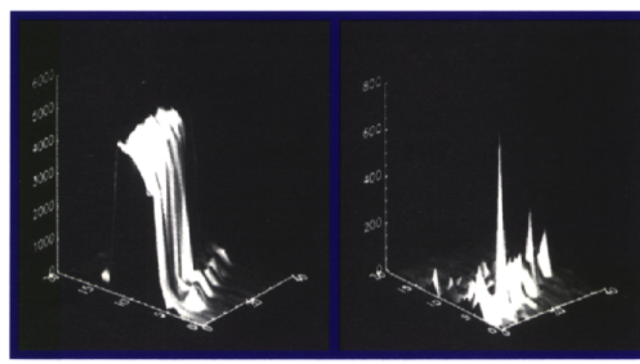
Innovation is another key to success. For example, BES developed a new class of "reusable" resins that selectively remove heavy metals from chemical plant waste streams more efficiently than earlier products. Several companies are now using a BES-devised technique called "thermally enhanced soil venting" to improve the removal of volatile chemicals from contaminated sites. Researchers found that even modest soil temperature increases, achieved by hot-air injection, can considerably enhance the separation process and thus lower the costs of remediation.

Probably the most desirable alternatives to conventional waste treatments are safe and effective bioremediation techniques that use natural processes to neutralize wastes. In one project, BES researchers are working with industry to develop an effective way to use a soybean enzyme that can break down PCBs and other toxic chemicals, Enzyme treatments have several advantages: one can easily access the target compound, very low levels of a pollutant can be treated, and the amount of enzyme used can be varied according to the concentration of the pollutant.



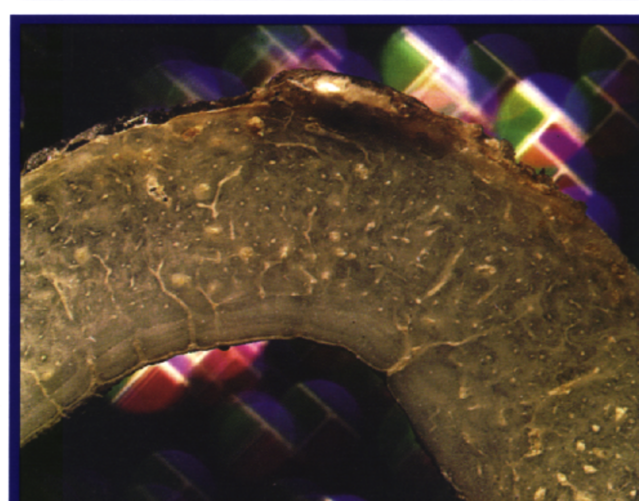
# Treating Waste

Argonne National Laboratory has developed a new method for treating waste that contains a mix of radioactive materials and other chemicals. This new method allows these mixed components to be more effectively separated and disposed of. In initial trials with an ion-exchange resin (developed by Argonne), the uranium in a waste solution not only was reduced 300,000-fold (to a level within the acceptable limits for drinking water), but also was subsequently extracted and purified. The Eichrom Company has since commercialized the process (pictured here).



# Contaminant Analysis

Scientists from the Westinghouse Savannah River Company are using X-rays from Brookhaven National Laboratory's National Synchrotron Light Source to study the location, concentration, and chemical form of toxic compounds within contaminated soils from nuclear processing facilities. The chemical sensitivity of the NSLS X-ray microscope is illustrated by these graphs, obtained by Brookhaven researchers, which show the distribution of strontium and lead in a 50-micron-thick section of human bone.



# Transportation

## vehicles for the future

Automobiles, aircraft, trucks, and vehicles of all types are essential to transportation in today's global community. But transportation also consumes a major portion of the world's energy and creates major environmental concerns. To continue moving people and goods from one place to another in the next century, we need vehicles that last longer, use energy more efficiently, and don't pollute the environment.

Developing and evolving vehicles to meet these critical goals require integrating complex assemblies of advanced materials, computer controls, and better fuel and emissions systems. BES is supporting these efforts through the science that enables these evolving technologies. Using alloy design, for example, scientists are developing new materials for magnets. In turn, these magnets are used in a variety of the sensors and small motors for power steering and other vehicle functions.

At BES user facilities, neutron beams probe the molecular arrangement of the rubber used in tires. The goal is to reduce the buildup of tire heat while in use — and thus increase fuel efficiency. Additionally, researchers are applying expertise in characterization and modeling to develop environmentally safe coatings that inhibit corrosion and rusting in car parts.

For aircraft and automobiles, wear-resistant coatings are being designed that build on basic science understanding of erosion. BES-developed technologies also provide a foundation for highly sensitive tools to analyze automobile emissions and guide the development of ultralow-emission vehicles.

Computers are also playing a key role. Automobile components are being engineered with guidance from computer models that optimize design — from auto body panels with reduced weight to taillights with nearly ideal optical properties. Aided by new parallel supercomputers, scientists are simulating faster and more accurate car crashes and using those data to design vehicles with improved safety features. The next generation of vehicles is coming, and BES is helping to pave the way.

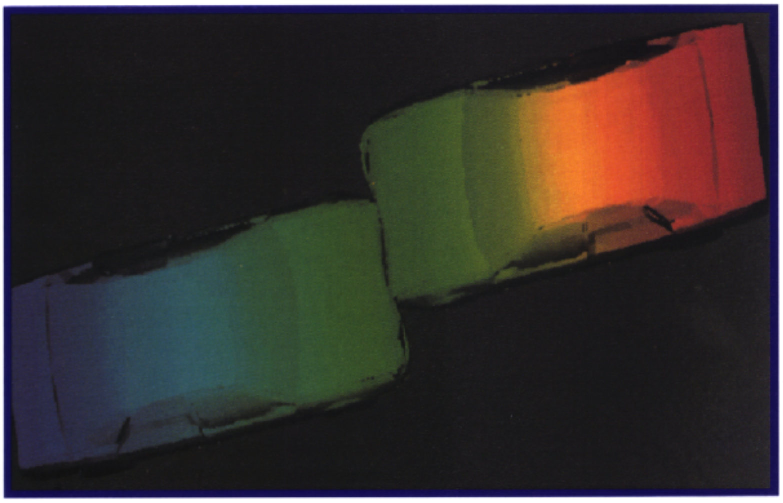

**Erosion and wear at high operating temperatures are major problems in engines in many transportation systems. Joint research between Argonne National Laboratory and AlliedSignal has improved the coatings technologies used in anodized aluminum for reducing erosion and wear in jet aircraft castings. This collaboration also includes the development of new silicon nitride ceramics for engine components. The extensive analytical expertise at Argonne has played an important role in these developments.**

# Ultrasensitive Detectors

An advanced ion trap mass spectrometer system, developed at Oak Ridge National Laboratory, is being commercialized by Teledyne Corporation for environmental analyses and explosives detection. This system also has a major role in a joint research effort (funded by the Advanced Energy Projects and Technology Division) with the U.S. auto industry to develop advanced technologies to measure automobile emissions in real time.

# Efficient Optics

Optical collectors, now being used by Ford for taillights in Thunderbirds, are based on designs developed by basic research at the University of Chicago. These designs enhance light concentration by more than a factor of 4 compared to traditional focusing techniques.

# Computer Simulations

To design better, safer, and more crashworthy cars, computer modeling is becoming increasingly important. Modeling reduces the need to conduct crash tests with real cars (these tests can cost as much as $750,000). However, using computers to simulate crashes takes a long time — typically several weeks. BES adapted new codes for the new massively parallel architecture supercomputers at Oak Ridge National Laboratory. With this new, faster computing capability, the run time for the crash model shown here was reduced to less than 26 hours. This modeling effort, which was a collaboration with the Department of Transportation, was the first automobile crash simulation performed with a parallel computer.

# Manufacturing

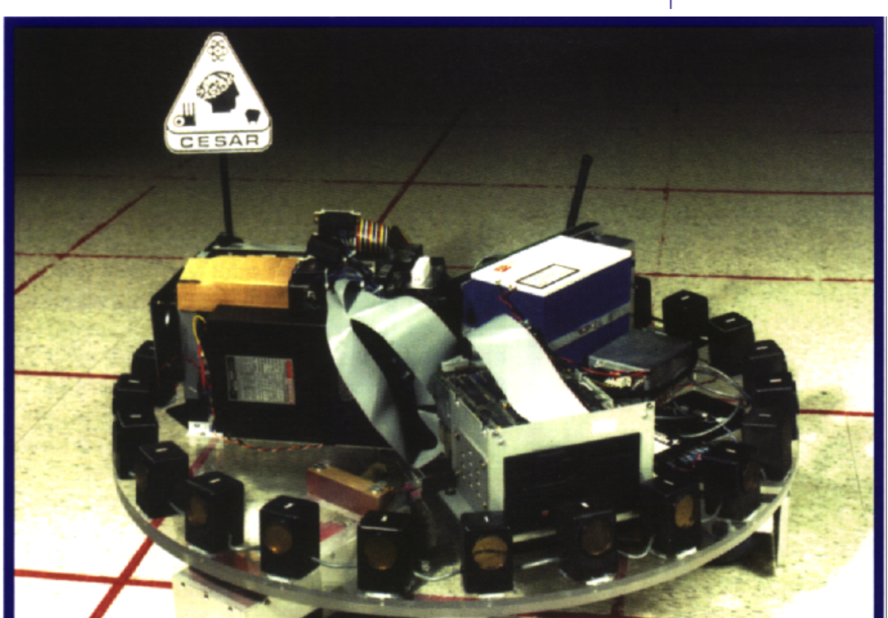
## science for advanced manufacturing technologies

A manufacturing revolution is under way. Today, effective manufacturing is concerned not only with low-cost and high-quality products, but with maximizing energy efficiency, minimizing pollution, and ensuring our safety and health. The current buzzwords include “life cycle engineering,” “computer-aided design,” “intelligent manufacturing systems,” “integrated manufacturing system,” and “concurrent process/product design.” Underpinning all of these are process models, sensors, and fundamental technologies that come from basic research.

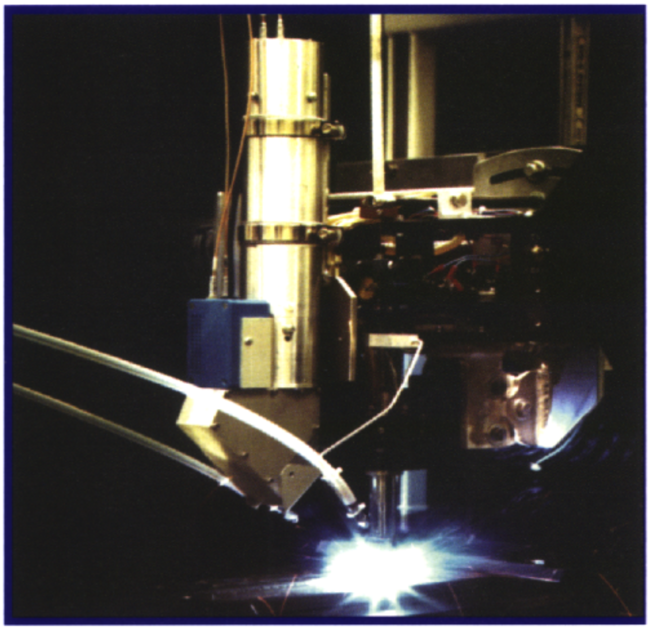
The ultimate goal is to design both the product and the manufacturing process on a computer, thereby eliminating much expensive trial-and-error prototyping and retooling of assembly lines. Understanding manufacturing well enough to simulate it on a computer requires complex models that incorporate accurate data from every step of the process. BES is a leader in developing intelligent sensing and models for thermal and deformation processing. Industry is incorporating these scientific tools in a wide range of manufacturing procedures, from welding and heat-treating to rolling sheet metal and fabricating complex shapes.

Reduction of scale is another challenge in today’s manufacturing environment. Electronic devices are fabricated on the micro- (or even submicro-) scale, where circuit components have features that are one hundred times smaller than the diameter of a human hair. Micromachines are being used more and more, such as on heads that can read ever-more-dense information on computer disks and in small sensors that monitor temperatures. Manufacturing these small devices requires elaborate techniques and advanced characterization for quality control. BES user facilities have served as partners with industry in developing these tools.

Concern for personnel and for the environment is also central in today’s manufacturing world. To this end, robotic systems are increasingly used in hazardous environments. BES is developing the advanced systems and software needed to advance robotics to meet the needs of the next century.




**Robotics — automated machines — are heavily used in a host of manufacturing processes. The BES-funded Center for Engineering Systems Advanced Research (Oak Ridge National Laboratory) has developed a new type of platform for mobile robots called the Omnidirectional Holonomic Platform. This invention, which received an R&D 100 Award, has stimulated nearly 100 inquiries from industry. The platform is currently being upgraded for commercialization through a collaboration with Nomadic Industries.**

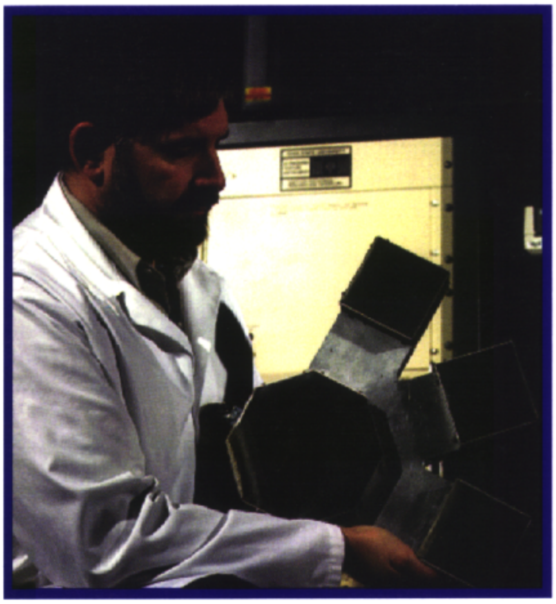


# Visualizing Welding

Welds are used to join metals in virtually all manufactured products. The laser-assisted welding vision system, developed at Idaho National Engineering Laboratory, provides significantly clearer images of the molten metal pools during welding than are possible with conventional video cameras. These images can be used for quality control diagnostics and computer control of the welding equipment, which results in higher quality welds. A spin-off company, Control Vision International, is in its sixth year of producing and marketing this system to the arc-welding and plasma spraying industries.

# Nondestructive Inspection

Tearing is a major concern in manufacturing components made from thin metal sheets (such as beverage cans or automobile parts). The Ames Laboratory multiviewing ultrasonic system (shown here) is being used to nondestructively inspect sheets to detect flaws during processing. Several industries, including aluminum companies, automotive companies, and steel producers, are collaborating to develop this technology.



# Micromachining

Both the scientific community and private industry are excited about the potential of micromachining technologies. The thermal sensor for automobile engines (shown here) was formed by deep-etch X-ray lithography at the Advanced Light Source, Lawrence Berkeley National Laboratory. This technique can produce robust micromachines that are simultaneously thick (1 mm) vertically and thin (μm) horizontally. Lawrence Berkeley, which is collaborating with Jet Propulsion Laboratories, is using this technique to fabricate precision devices used in X-ray astronomy.

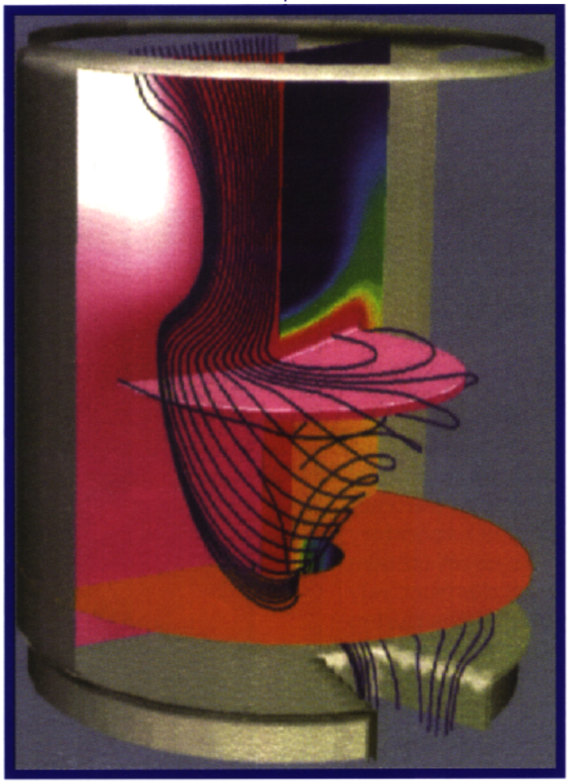
# Chemical Processing

**chemistry in our daily lives**

Processing technologies involving chemicals affect how we live in a number of ways, from growing and preparing foods, to generating energy, to manufacturing cars and semiconductors. Understanding and improving these processes are challenging multidisciplinary problems. BES research is providing the scientific underpinning needed for chemical processing technologies that meet the demands of both industry and society: high quality with minimal environmental impact, minimum cost, and maximum efficiency.

The quality of industrial processes — whether pharmaceutical manufacturing or environmental analysis — hinges on simple and effective mixing of ingredients. Basic chemical research in BES-supported laboratories has provided new approaches that have raised mixing efficiencies more than tenfold.

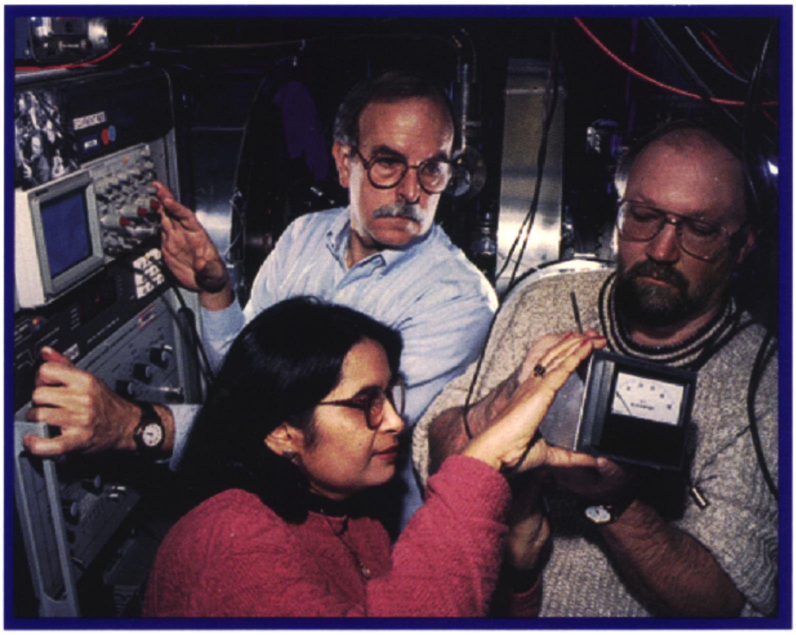
Most chemical processes take place in containers and involve transporting liquids or gases through pipes and other conduits. BES research, a major contributor to chemical processing, is helping to control corrosion through coatings and solution chemistry. BES innovations include microscopic coatings for enzymes and catalysts to protect them from harsh industrial environments, thereby extending their lifetime and effectiveness.



**Various industries are using a computer model such as this one, developed to study the fundamental chemical interactions that occur during chemical vapor deposition (CVD). CVD is an important technological processing technique used in fabricating semiconductors and other types of thin films. Since 1990, Sandia National Laboratories has distributed more than 200 copies of this modeling software, called "Surface Chemkin," under a no-fee licensing agreement. This model shows the profiles of the chemical species and thermal gradients in an Emcore CVD epitaxial growth reactor.**

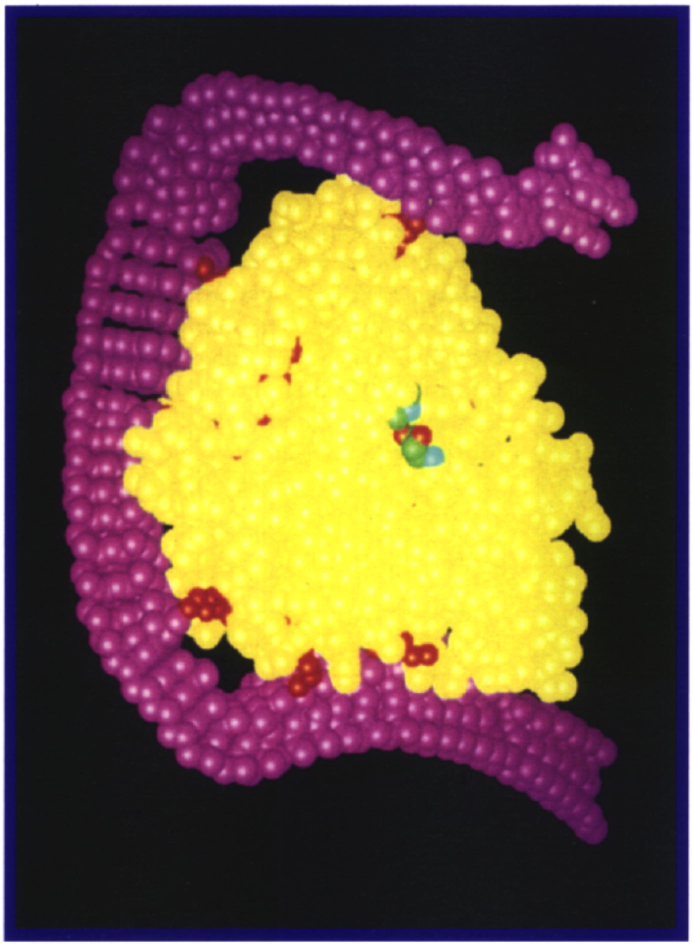
Today, industry is moving toward computer design of chemical processes. BES models of chemical interactions are playing a key role in this activity. Industries are already using models of gas-surface reactions to guide and control combustion reactions and a host of industrial chemical processing and environmental abatement technologies.

BES researchers and user facilities are also working with industry using advanced characterization techniques to identify defects that limit lifetimes of catalysts, paints, and a wide range of related products. Correlating these microscopic features with controlled variations in processing and operational conditions is challenging, but it is leading to enhanced understanding — and hence, improving — process chemistry.



# Analyzing Coatings

A real challenge to the paint and building industries is determining the lifetimes of painted surfaces exposed to weathering. Brookhaven and Oak Ridge National Laboratories, working with the Masonite Corporation, have developed a new technique that allows the effects of weathering to be detected and characterized. Using positron annihilation techniques, researchers detected defects in painted surfaces after only one week of weathering. Earlier techniques required a minimum of one year exposure before defects could be detected. This photo shows the positron annihilation facility at Brookhaven.



# Protecting Enzyme Catalysts

Enzymes valued at billions of dollars per year are used as catalysts in industrial processes, in pharmaceuticals, and as specialty chemicals. Lawrence Berkeley National Laboratory has developed a novel carbohydrate-based polymer, Carbohydrate Protein Conjugate, that stabilizes a wide variety of proteins, including enzymes and antibodies. The polymer does this by wrapping around the protein surface and providing a unique and stabilizing microenvironment. The coatings allow enzymes to remain active in hostile industrial environments and prolong their useful lifetimes. This material, developed in conjunction with Cargill Incorporated, was the winner of an R&D 100 Award and is now commercially available from Sigmachemical Company.

# Biotechnology

## unraveling nature's secrets

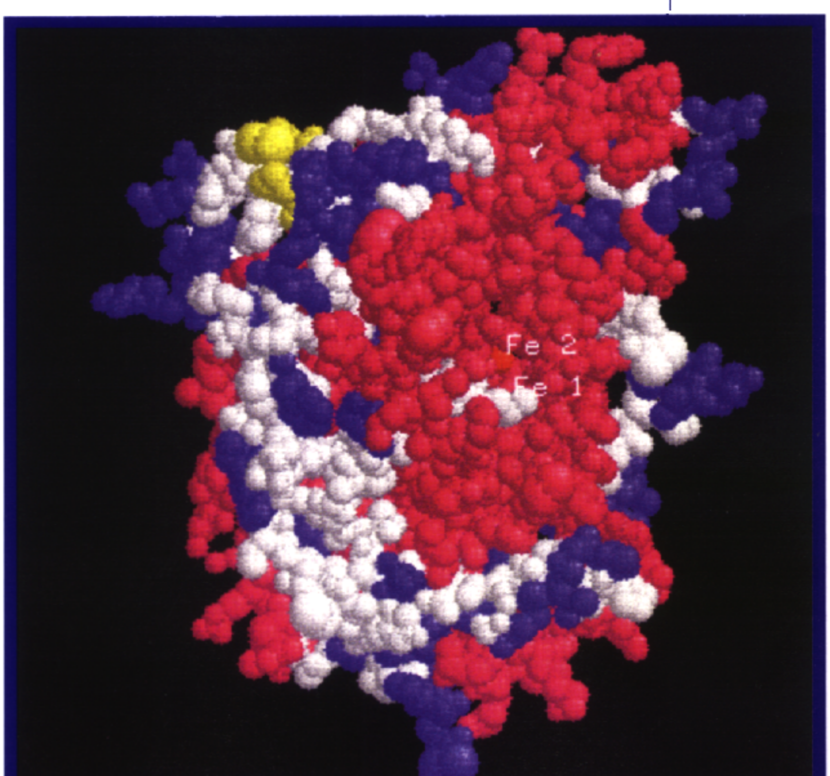
Many separate breakthroughs in molecular genetics and molecular biology led to the current revolution in biotechnology. BES is contributing to this revolution through its biosciences programs, development and use of innovative imaging techniques, and the advanced capabilities of its national user facilities.

Genes isolated and studied by BES scientists are furnishing the medical, industrial, and agricultural sectors with new tools to serve humankind. For example, scientists are now using a number of plant genes to increase the biosynthetic production of the new anticancer drug Taxol (found in Pacific yew trees). In another research effort, a gene that protects corn plants against the European corn borer has been transferred into the plants themselves, thus reducing the need for pesticides. Finally, the development of the model plant *Arabidopsis thaliana* and the sequencing of its genome have yielded both herbicide-resistant plants important for agriculture and plants with altered lignins useful to the pulp and paper industry.

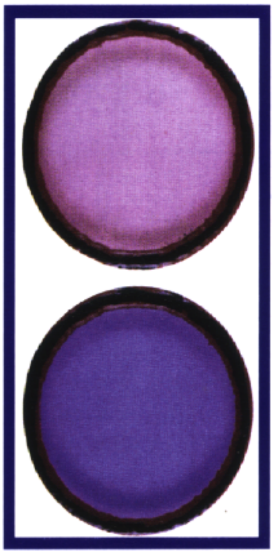
Scientists are also studying a whole new way to manufacture plastics — in plants! If researchers can commercialize this process-in which a gene allows certain kinds of bacteria to manufacture biodegradable plastic in the plant — plastics, which are so important in today's world, can be manufactured in an environmentally friendly way.

BES work has also laid the foundation for developing analytical imaging and diagnostic technologies that can be applied to biological systems. These technologies include single-molecule detection for analyzing nucleotides from DNA and double-mass fragmentation spectroscopy for determining the structure of protein, DNA fragments, and carbohydrates. In addition, BES studies of radioactive atoms led to the synthesis of one of the most widely used positron emission tomography tracers in the world for clinical research and diagnosis.

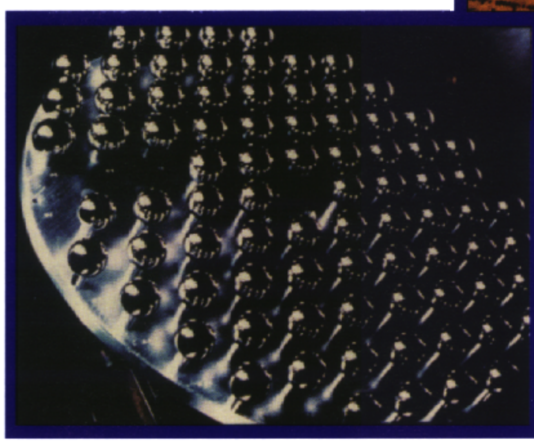
Many biological researchers and companies are using BES synchrotron facilities to collect detailed information about the three-dimensional structure of biological macromolecules. This new information in turn has led researchers to design new enzymes that produce inexpensive fuels and chemicals.




**Researchers at Brookhaven National Laboratory have used data on protein structure to design a new enzyme that can be engineered into biological systems. The new enzyme allows researchers to synthesize a new lipid (a class of compounds useful in a number of chemical-related industries).**



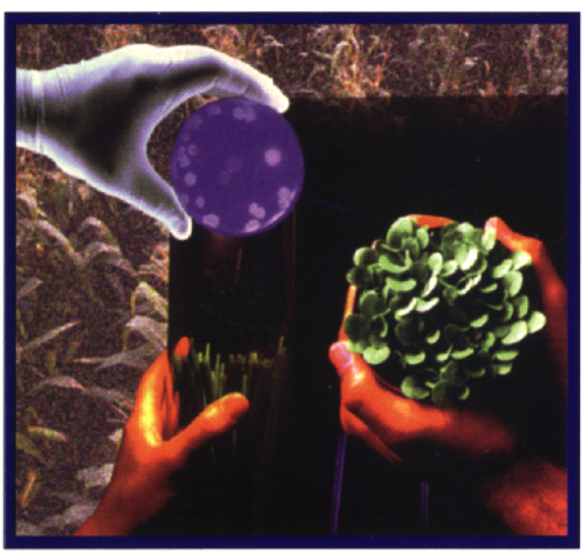
With a simple color change from blue to red, a monomolecular film created by researchers at Lawrence Berkeley National Laboratory signals the presence of biological or environmental entities. These sensors could be used to identify substances ranging from toxic compounds to bacteria and viruses.



Inset: Spire Corporation prepares the "balls" for artificial hip joints for ion implantation. The large tilt-rotation platen allows nearly 100 orthopedic devices to be processed at one time.

# Ion Implantation

Each year, more than 100,000 artificial hips, knees, and other orthopedic devices are manufactured using an ion implantation technique developed by Oak Ridge National Laboratory and the University of Alabama at Birmingham. This surface treatment, which dramatically improves wear resistance, has now been implemented by several companies for a variety of orthopedic applications.

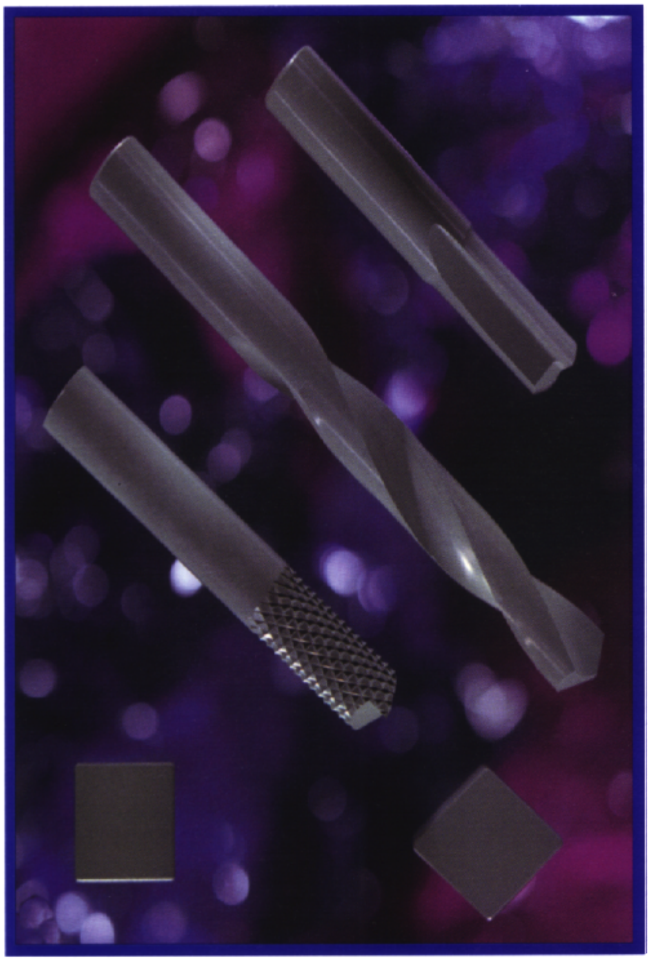


# Plant Biotechnology

Plants and photosynthetic microorganisms are solar energy transducers that produce fuels and useful chemicals. BES supports fundamental research at the Michigan State University/DOE/Plant Research Laboratory into the mechanisms of how plants grow, metabolize, and reproduce. This research provides the foundation for the use of biological systems in energy-related technologies ranging from the production of liquid fuels to the synthesis of biodegradable plastics.

# Ceramics

## beyond pottery, whiteware, and dishes



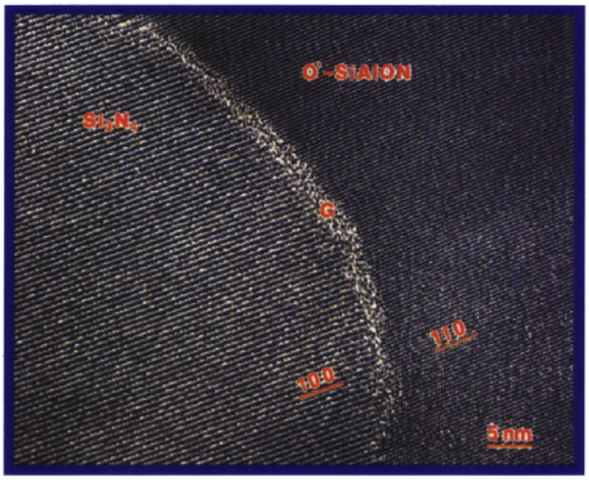
Researchers at Oak Ridge National Laboratory have developed a new tough ceramic that has had far-reaching effects on the cutting tool industry. Using these new ceramics, machining rates have been increased by up to 800 percent. The discovery of these ceramics, an alumina composite reinforced with silicon-carbide whiskers, was based on BES research into ways to toughen ceramics and supported by DOE's Energy Efficiency Programs. This material, which has been licensed to a number of companies, has current worldwide sales of over $30 million. The cutting tools shown here are from Advanced Composite Materials Corporation.

Ceramics keep their strength at high temperatures, are lightweight, and often have excellent thermal and electrical properties. But anyone who has ever dropped a dish knows why these brittle materials have not been more widely used. Although ceramics are never likely to replace metals in all applications, ceramics are now tough enough — thanks to BES-sponsored basic research on combatting brittleness — for use in hammers, high-speed cutting tools, engine turbines, and sports equipment.

One of the ways to toughen a ceramic is to reinforce it with fibers or small whisker-like additions, much like strengthening concrete with steel bars. Industry and others are now using BES models of toughening mechanisms, coupled with insights gained from characterizing the quality of the interfaces between the fibers and the ceramic matrix and the chemistry that goes on there, to make better ceramic automobile parts, cutting tools, and fabrication dies.

Structural ceramics begin with a powder, which is mixed with a liquid binder, shaped, and sintered at high temperatures. Electronic and optical applications often require large crystals with perfectly aligned atomic structures. BES is making a difference across the board. BES researchers have developed synthesis technologies for powder particles in high quantities, ceramics with uniform diameters and high purity, and methods to grow perfect crystals to larger sizes, all at low cost.

Because of their hardness, ceramic coatings — especially diamond and diamond-like coatings — help to reduce the wear of materials. At BES user facilities, characterizing the complex microstructures of these coatings is helping to gain a scientific understanding of how they work and is aiding in their commercialization.

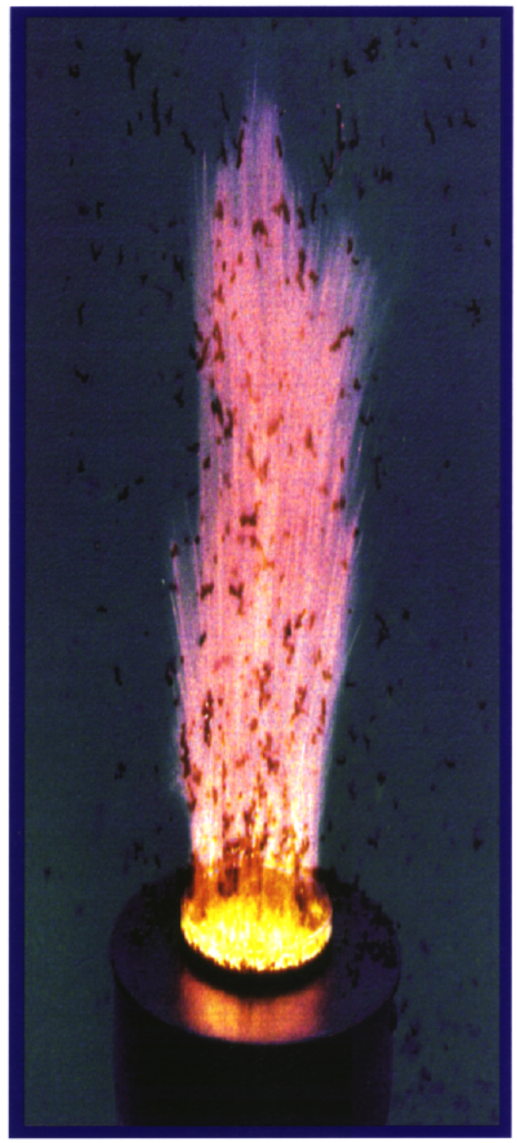



# Atomic-Scale Microscopy

(left) The interfaces between reinforcing fibers and the brittle ceramic matrix frequently control the properties of a ceramic composite. Researchers from industry often use the sophisticated characterization tools available through the BES microscopy centers to correlate the properties of ceramics with the structure at the interfaces. Shown here is a high-resolution electron micrograph of a glassy layer in a silicon nitride-silicon aluminum oxynitride (SiAlON) composite from the University of Illinois Materials Research Laboratory.

# Powders

(right) A process developed by Pacific Northwest National Laboratory allows simple, low-cost fabrication of clean ceramic powders with a fine particle size and good homogeneity. The winner of an R&D 100 Award, this process has now been commercialized by Praxair Specialty Ceramics for solid oxide fuel cells and other energy-efficient devices. The photo here shows the lab-scale powder production process.



# Crystals

(above) Today ceramics are used in a number of electronic applications. Many of these applications require large, perfect "single crystals" of the ceramics. Researchers from Los Alamos National Laboratory and Advanced Ceramics Corporation have fabricated large single crystals — up to 10 mm in length and 5 mm in diameter-of silicon nitride. Potentially, these crystals can be used for insulators, imaging tips in scanning tunneling microscopes, and indenters for microhardness systems that operate at high temperatures.

# Electromagnetism

## the key to a new wave of high–tech products

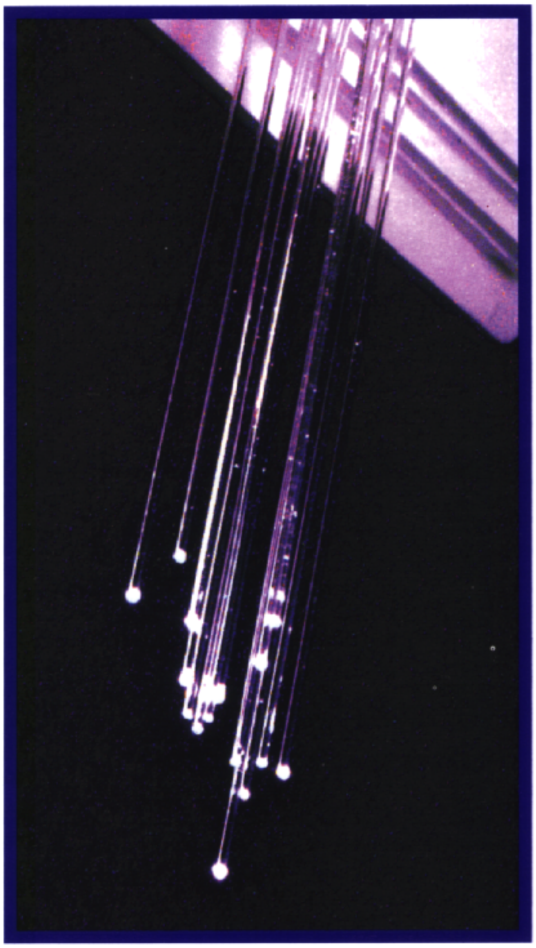
Electricity, magnetism, and light waves are all aspects of electromagnetism, one of the fundamental forces of nature and the one most directly involved in the technology we use to enhance our lives. BES scientists are using their knowledge of electromagnetic phenomena to help industry bring forth a host of high-tech products that span the information superhighway, national security, the environment, and energy efficiency.

The demand for increased capacity to store computer data grows at least as fast as advancing computational power. Some BES-sponsored research is aimed at innovative technologies with the potential for higher storage capacity than presently available, while other projects seek to upgrade substantially the performance of conventional magnetic disks with new magnetic materials and protective coatings.

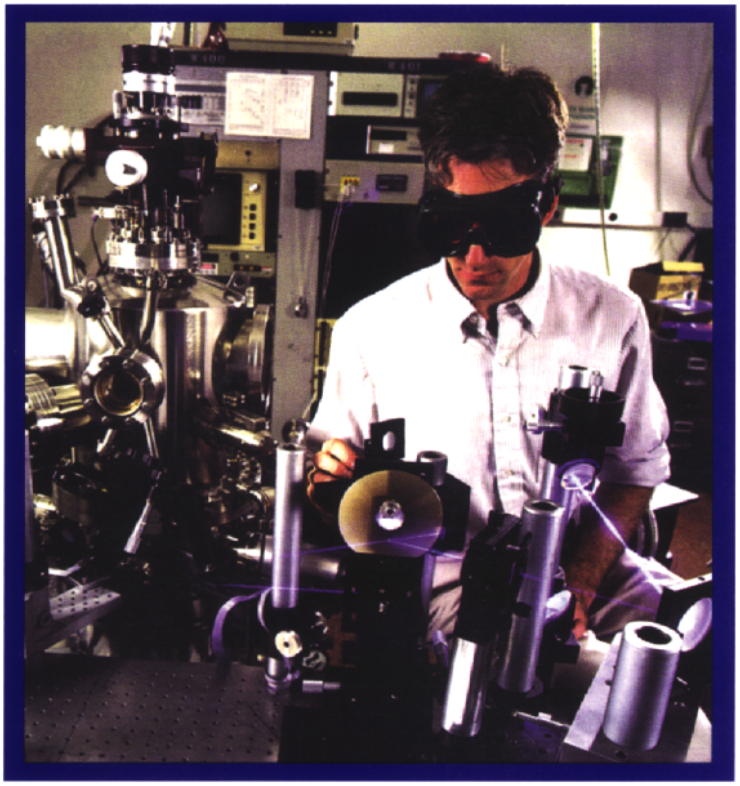
Optical communication, which has already replaced older technology in some of the Nation's telecommunications systems, is the key to high-capacity data transmission on the information super-highway. BES scientists are making important contributions with work on optical fibers and cables, lasers, and optical materials for guiding and manipulating light waves.

Since they burst on the scene in the research laboratory three decades ago, lasers have become the light source of choice for an immense variety of uses. BES researchers are working to perfect high-power lasers and develop lasers that can be tuned to any wavelength within a broad spectrum. They are also working on high-efficiency solid-state lasers and their cousins, light-emitting diodes.

Solar cells and photo detectors work by the same principle — the absorption of light waves generates an electric current or voltage. In the renewable energy field, work at BES laboratories is leading toward advanced solar cells. At other BES facilities, efforts are under way to improve infrared-detector materials and devices for remote environmental monitoring and satellite surveillance.

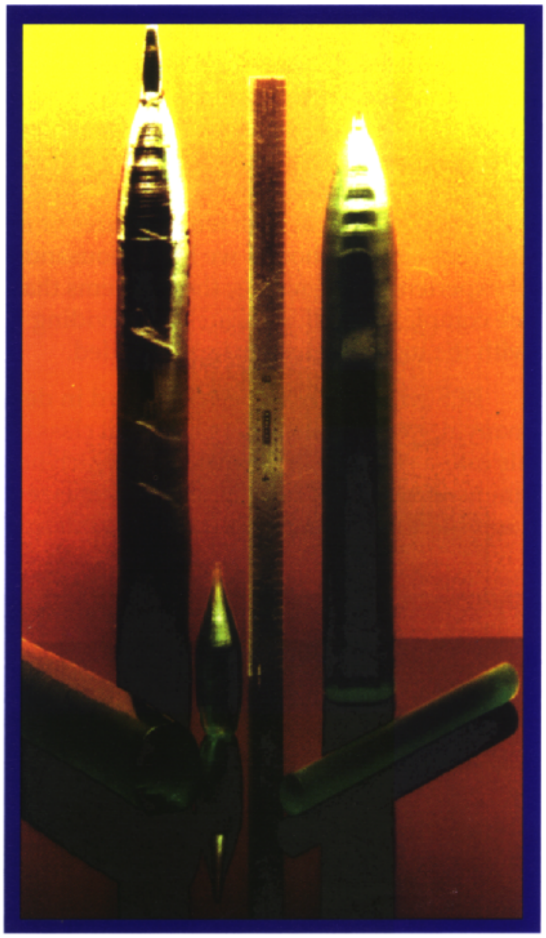


**These lead phosphate glass fibers are resistant to corrosion and weather. Because they collect almost all the light injected into them, they potentially can be used for optical communication on the information superhighway and for other light-guiding applications. The same innovative technology from Oak Ridge National Laboratory has been licensed to Komwave Corporation for use in making glass-to-metal seals.**



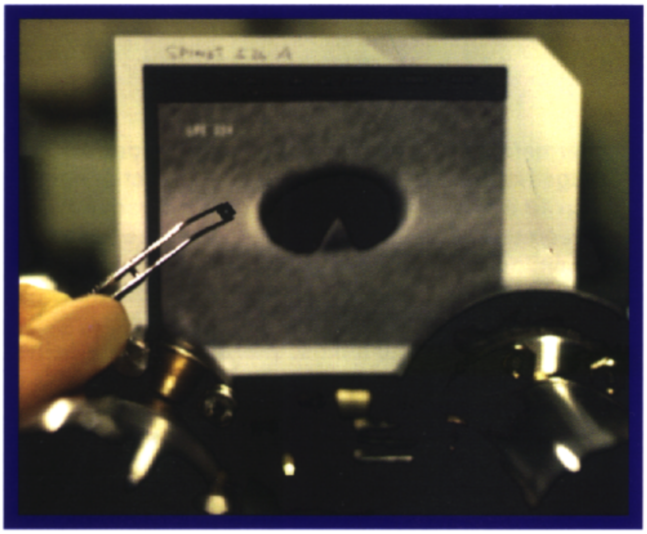
## Carbon Coatings

(left) Making and evaluating the carbon coating that protects computer hard disks are key requirements for increasing the storage capacity and reliability of magnetic storage devices. In collaboration with Seagate Magnetics, Lawrence Berkeley National Laboratory has developed a laser technique that reduces the need for destructive, time-consuming mechanical testing of the coatings.



## Solid State Lasers

(right) A research team at Lawrence Livermore National Laboratory has developed a new class of solid-state laser materials with superior properties for operation over a wide wavelength range at high power levels or with ultrashort pulses. The technology has been licensed to several companies, including Lighting Optical Corporation, that market the materials to laser manufacturers.



## Flat Panel Displays

(left) Ames Laboratory and Amoco Technology Company are researching new flat-panel displays. These devices are based on the emission of electrons from arrays of tiny conical tips, such as those shown in the electron microscope image behind the tweezers holding a test array. This field-emission technology promises resolution comparable to conventional displays combined with higher brightness.

# Metals, Alloys, and Intermetallics

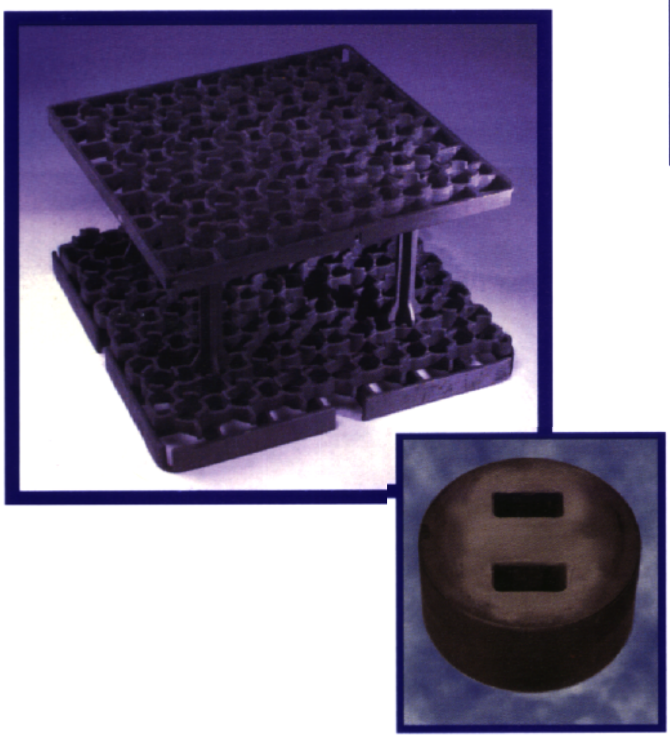
## materials for today... and tomorrow

Even with increasing use of plastics and ceramics, metals and their alloys still make up most of the structural materials used today in cars, girders for buildings and bridges, wire, pipes, and a wide range of other commercial products. Metals, however, have limitations: some rust, some are heavy, and some weaken at high temperatures or in severe environments. Although we have thousands of years of experience with metals, the problems that remain are complex; but BES research is providing industry with the tools and new insights needed.

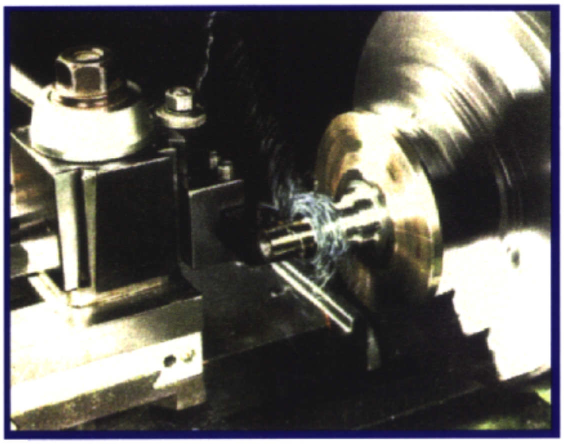
BES scientists have been involved in developing many new alloys, including a special class of materials called structural intermetallics, which have the unique property of becoming stronger as temperatures increase. Historically, however, intermetallics have had one major problem: they were very brittle, especially at room temperature. BES alloy science helped unlock the secret of making intermetallics ductile so they do not fail easily or catastrophically, and so they can be machined into needed shapes. Today, a number of commercial products are available and/or under development.

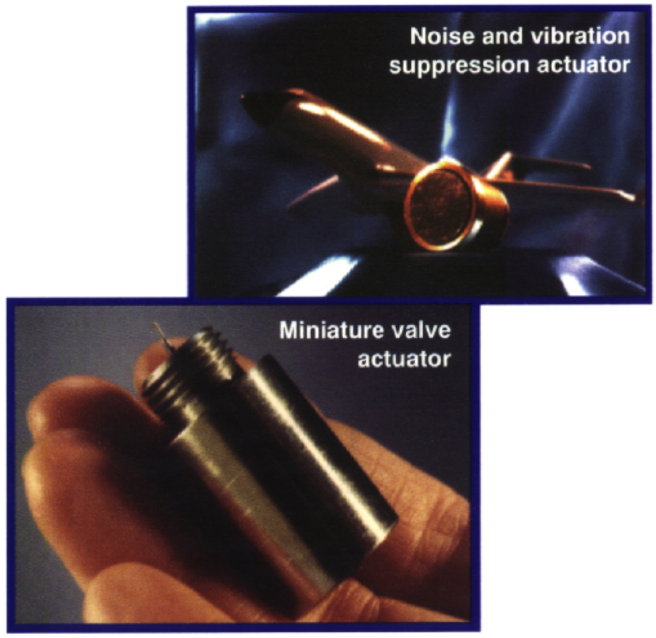
BES research also has developed new steels, improved aluminum alloys, magnet materials, and other alloys. As an outgrowth of surface science research, coatings and special surface-modification technologies are being used to enhance the wear and corrosion resistance of metals. In the environmental arena, BES is leading the way to develop improved and lead-free solders that are used extensively in manufacturing semiconductors.

Modeling and first-principles alloy design are other areas in which basic science is making important contributions to aluminum and other metals processing. Industry is using BES computer codes that can predict the changes that metals undergo during fabrication to improve products and reduce costs.



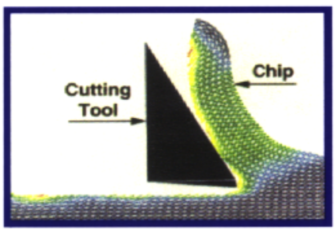
**Intermetallic alloys, based on research done at Oak Ridge National Laboratory, are the subject of more than 10 licenses and a number of cooperative agreements with industry. Shown here are nickel aluminide furnace fixtures and dies that are commercialized or are under testing in an industrial setting. The trays (left) are greater than twenty times the size of the molds. Intermetallics are being used in high-temperature applications where they last five- to ten times longer than superalloys. Intermetallic research has evolved under an integrated basic and applied research effort funded by BES and DOE's Energy Efficiency and Fossil Energy programs.**





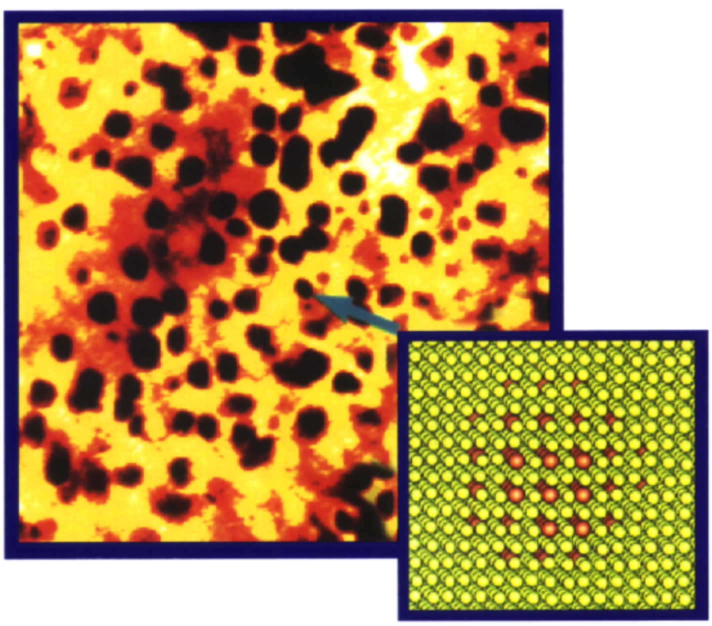

# Machining Metals

Using fundamental models that describe how metals deform, Los Alamos National Laboratory is collaborating with a major automobile manufacturer to improve the manufacturing process of metal cutting. Shown here is the computer model for forming metal chips with a cutting tool, along with a photograph of the actual process. As part of a collaborative relationship funded by DOE Defense Programs, the models developed by Los Alamos are being validated by comparing them with machining data generated in an industrial setting.




# Shape Changers

Some commercial products, such as the ones shown above, use “Terfenol,” a material that changes shape when exposed to magnetic fields. When that happens, this material, developed by Ames Laboratory and the Naval Surface Warfare Center, undergoes dimensional changes that exceed those of other commercial magnetostrictive materials by a factor of 10. A new company, ETREMA Products, Inc., was established to commercialize products made from Terfenol; the company now employs more than 20 people.



# Atomistic Simulations

Atomistic simulations, developed at Sandia National Laboratories to understand fundamental alloy properties, are being combined with Alcoa’s models for manufacturing aluminum. The aim is to obtain a code that will aid in developing new aluminum alloys and designing the processes to make these alloys. The figure combines experimental evidence of aluminum scandium precipitates (the micrograph) with calculations that predict the formation of spherical precipitates (the red circles are scandium atoms; the yellow are aluminum atoms).

# Polymers

## more than rubber, rayon, and plastic

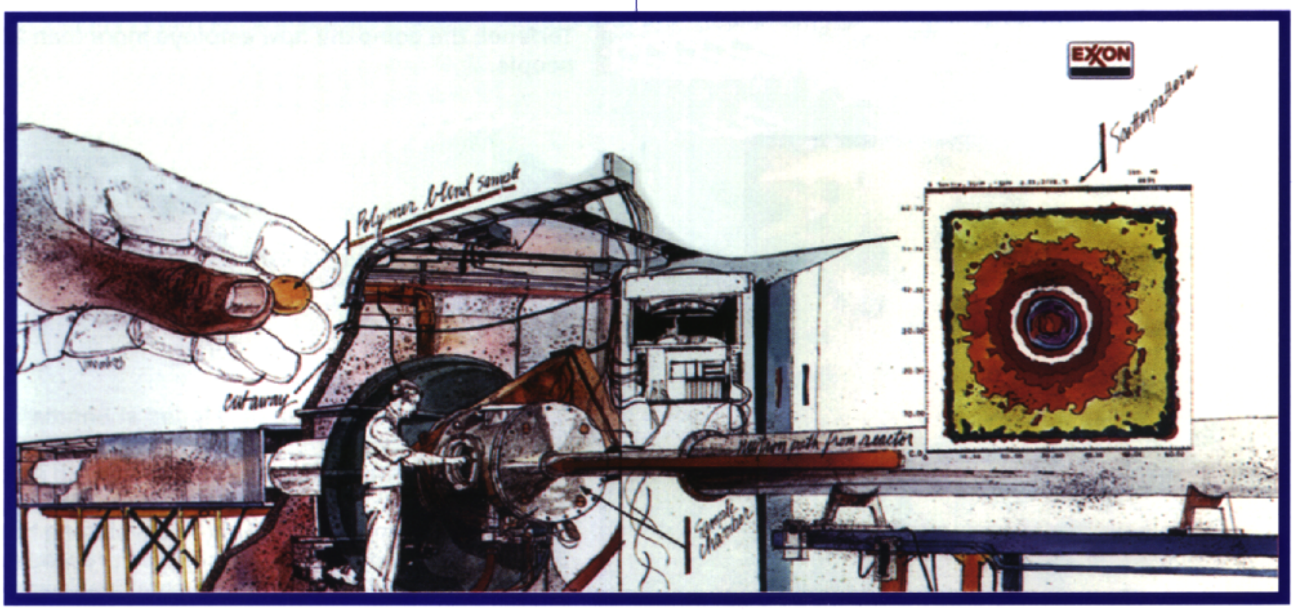
Synthesized from petroleum feedstock, polymers first gained public notice in the form of artificial rubber for tires, nylon and its offshoots for garments, and plastics for toys and containers. With the help of BES-funded research, companies are constantly searching for and finding new and improved polymers, as well as innovative ways to use these all-purpose materials.

Powerful BES computers and analytical tools can predict and measure the composition and structure of the basic polymer (long-chain) molecule, the ways in which the chains fold and link up as they take on solid form, and the ability to mix and blend different polymers synergistically to combine the best properties of each.

Reinforced concrete is a prototypical composite material; it's made from a strengthening element — in this case, steel — embedded in a matrix that provides it a basic structure. BES scientists are working with their industrial colleagues to perfect ways to manufacture polymer composites (modeled after concrete). One example is polymer-ceramic composites that serve as lightweight, flame-retardant structural materials for aircraft and housing.

Anyone with a non-stick frying pan appreciates that coatings provide another way to combine the good features of polymers with those of other materials, but they also understand that the quality of the bond between the coating and the underlying substrate determines the usefulness of the product. BES researchers are working to develop new bonding techniques for products from microchip packages to large structural parts.

The automobile of the future may be far more plastic than it already is, thanks in part to BES-supported research. Prospective uses for polymer materials include rechargeable batteries, flat-panel displays, wear-resistant plastic parts, and polymer-coated particles in lubricating oils. The fuel efficiency that goes with reduced weight is critical to maintaining and strengthening the market share of the U.S. automotive industry.



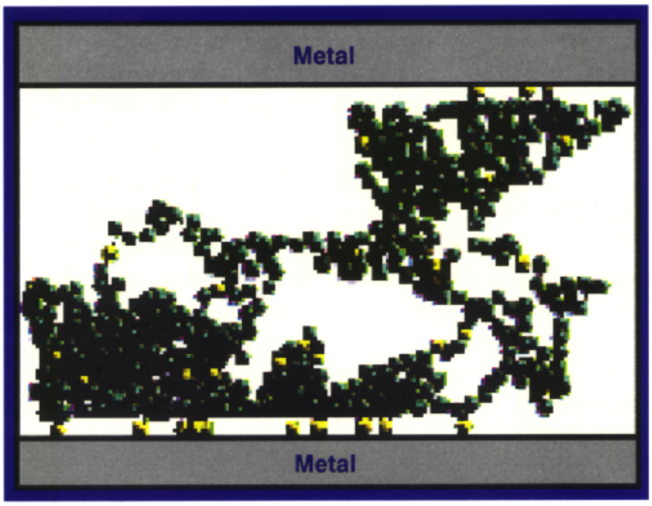

**Industry increasingly has explored combining (blending) polymers to achieve new materials with improved properties. Research at the small-angle neutron scattering facilities at the Oak Ridge National Laboratory's High Flux Isotope Reactor has led to significant advances in the understanding and design of polymer blends for more than a dozen companies, including Exxon.**

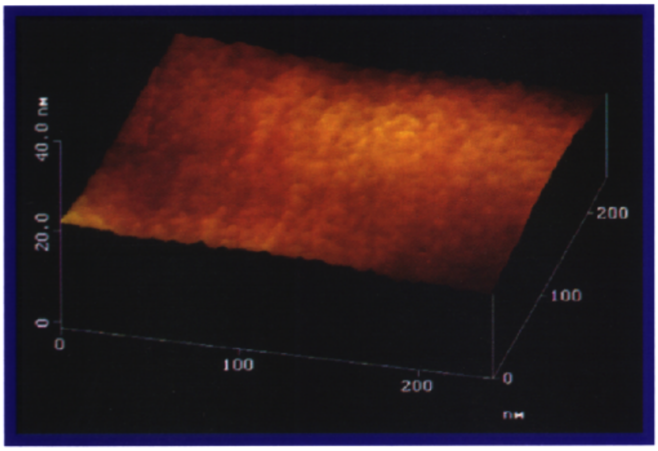
## Advanced Batteries

Brookhaven National Laboratory and the Moltech Corporation worked together under a cooperative research and development agreement to evaluate polymers for use in rechargeable lithium batteries as electrodes and electrolytes to conduct lithium ions between the electrodes. The polymers developed at Brookhaven for this purpose are much lighter than metal electrodes and have far higher conductivity than other materials.

## Adhesives

In research supported by Alcoa, Amoco, Ford, Inland Steel, and UTC, scientists at the University of Illinois Materials Research Center are investigating how polymer molecules are bonded to metal surfaces with the goal of making stronger adhesives, as in this computer simulation of a polymer adhesive between metal plates being pulled apart.




## Polymer Composites

Pacific Northwest National Laboratory has developed a new water-based processing method for making polymer-glass composite materials. This new method is environmentally and economically advantageous, compared to current practices. It also results in increased uniformity, enhanced performance, and ease of fabrication because of the fine grain structure, which is evident in this image taken with an atomic force microscope.

# Semiconductors

## paving the information superhighway

Until the middle of this century, silicon was best known as an ingredient of the sand found on every beach and used in glass-making. Now, purified, refined, elemental silicon is the basis of the famed semiconductor that launched the microelectronics revolution. BES researchers are deeply immersed in making sure that silicon and other semiconductors are up to the task of paving the information superhighway.

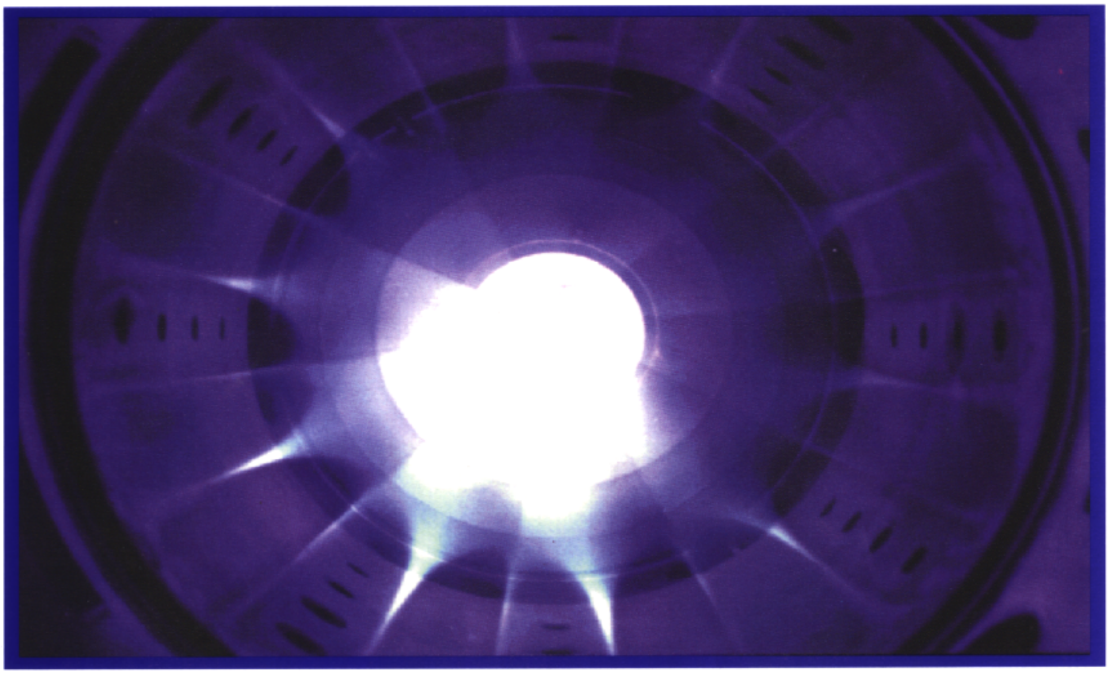
From the first microelectronic chips three decades ago, ever-increasing miniaturization has fueled a relentless march to higher computing power and lower cost. BES-supported researchers are providing industry with the facilities needed to develop patterning tools that further shrink circuit dimensions to the submicroscopic scale.

To sustain the pace of miniaturization, it is equally vital that the purity of the silicon be increasingly refined, especially to eliminate impurities near the surface where the circuit patterns are laid down. As conventional analytical techniques reach their limits, new X-ray methods, developed with the aid of BES facilities, promise to identify and quantitatively measure the unwanted impurities at the required sensitivity.

BES researchers likewise work in partnership with industry to identify the causes of and find solutions for other obstacles that snarl the way to successful miniaturization. Surfaces, for example, must be smooth to nearly atomic dimensions in order to ensure continuity between circuit elements. In addition, once imprinted, patterns are susceptible to disruption when the constituent atoms move away from their intended positions.

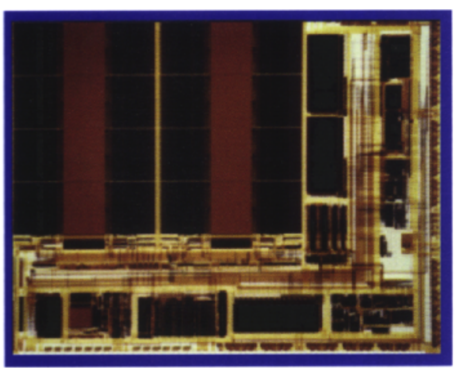
Though silicon has a combination of properties that make it a nearly ideal match for its microcircuit role, it nonetheless cannot do everything. Consequently, BES researchers are leaders in the search for new semiconductors with enhanced capabilities. Materials that show promise are gallium arsenide, gallium nitride, silicon carbide, and diamond, as well as silicon in modified forms such as thin films on substrates made from a different material and alloys containing silicon.

**Based on 10 years of successful experiments at Brookhaven National Laboratory's National Synchrotron Light Source, IBM has built its own X-ray lithography facility and begun producing fully functional devices. In X-ray lithography, advanced computer chips are imprinted on silicon wafers with circuit patterns using synchrotron radiation as the X-ray source.**



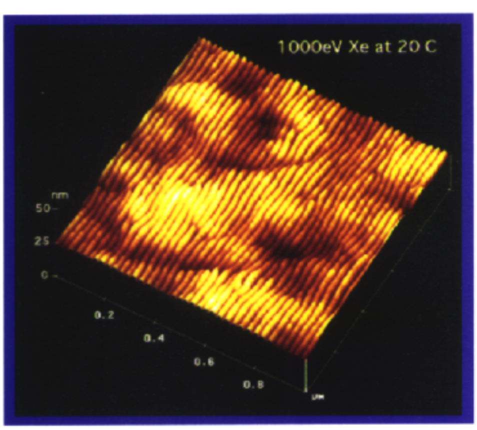
# Plasma Processing

During the processing of computer chips, plasmas (the bluish glow in the photo) created by microwave heating can both etch away unwanted material and lay down new material. Oak Ridge National Laboratory teamed with ASTeX, PlasmaQuest, and the University of Cincinnati to develop a new plasma source for a SEMATECH advanced plasma processing program.



# Analyzing Impurities

(left) Fabricating future computer chips with features that are less than 0.1 microns will require that metal contamination on the surface of silicon wafers be less than one part in 100 million. Hewlett-Packard, Intel, Fisons Instruments, and the Stanford Synchrotron Radiation Laboratory are working together on a new X-ray technique to measure such tiny quantities.




# Measuring Surface Roughness

A collaboration between SEMATECH and Sandia National Laboratories led to developing tools for characterizing near-atomic-scale surface roughness of silicon wafers during fabrication of computer chips, such as the silicon dioxide-covered surface shown in this atomic force microscopy image.

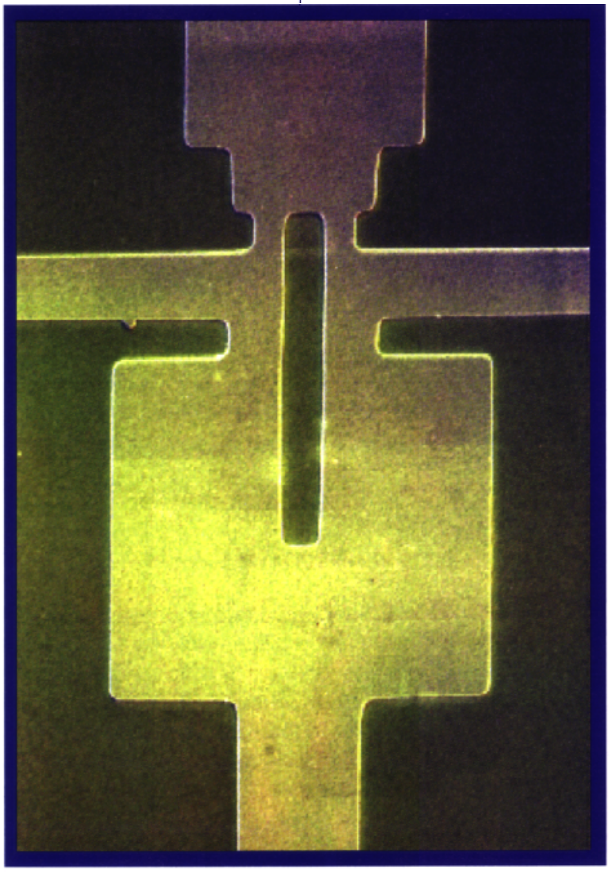
# Superconductors

## advancing the revolution

Superconductors have the ability to carry electric currents with little or no loss of power. This makes them ideal candidates for use in an expansive arena of applications such as ultrasensitive sensors and massive cables for electric power transmission. BES researchers have a long history in the search for improved superconductors that can be manufactured in forms useful to industry.

For example, superconducting wires power the magnets used in the magnetic resonance imaging machines that create refined images of the human body. BES researchers perfected a method for making wires of a high-performance superconductor that can generate strong magnetic fields while simultaneously remaining ductile enough to be easily formed into cables and other desired shapes. Currently, all U.S. manufacturers of this alloy use the BES-developed process.

The primary drawback for traditional, metallic superconductors is the requirement that they be refrigerated to ultralow temperatures (near absolute zero). In 1987, a superconductor revolution began with the completely unexpected discovery of an entirely new family of ceramic superconductors that required much less cooling. Since then, BES researchers have frequently been at the forefront of attempts to expand the family of superconductors and to further enhance their performance.



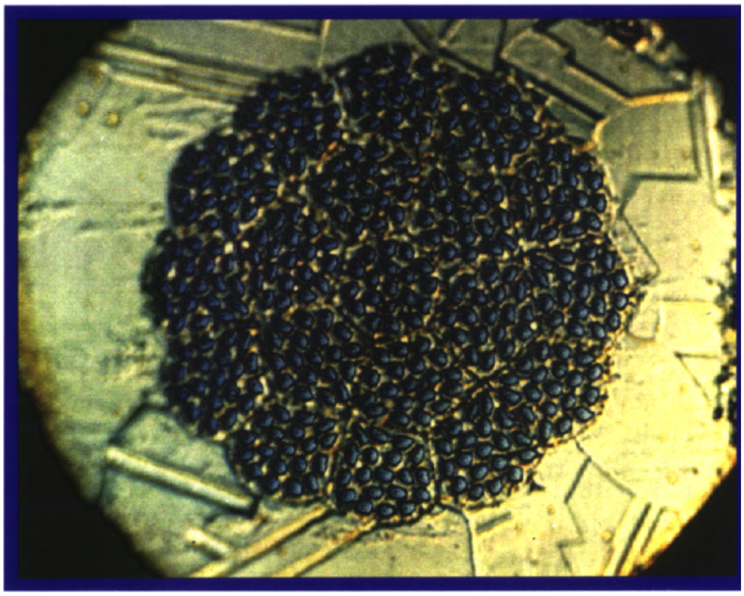
**In collaboration with Lawrence Berkeley National Laboratory, Conductus, Inc., plans to market the first practical application of the new high-temperature superconductors. The device is a magnetometer capable of measuring minute magnetic fields such as those emanating from the human heart and brain. The SQUID can also be used for nondestructive evaluation of materials for hidden flaws.**

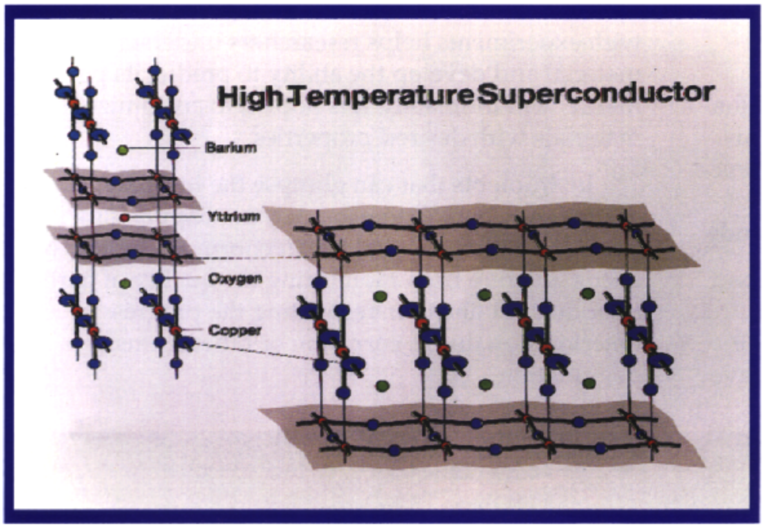
Because they are ceramics, the high-temperature superconductors are more brittle and harder to form than their metallic predecessors. Nonetheless, BES scientists are successfully working with their industrial counterparts to find innovative processes for manufacturing ductile wires, such as composite structures comprising strands of the superconductor embedded in malleable metal sheaths.

BES research has also hastened the introduction of the first high-temperature superconductor products. For example, an apparatus with the jaw-breaking name, “superconducting quantum interference device” — SQUID for short-can sense the minute magnetic fields that emanate from the human brain and heart, making it a candidate for use in demanding applications, such as non-invasive medical diagnoses.

# Niobium Tin Wires

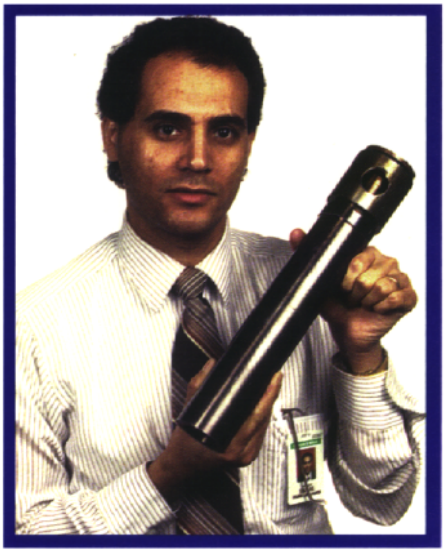
Researchers at Brookhaven National Laboratory developed an innovative method for making niobium-tin superconducting wire, which powers high-field magnets. This processing method is currently used by all U.S. manufacturers of this material. The wires consist of tiny fibers of superconductor (blue in the photo) imbedded in a copper alloy (bronze) matrix.





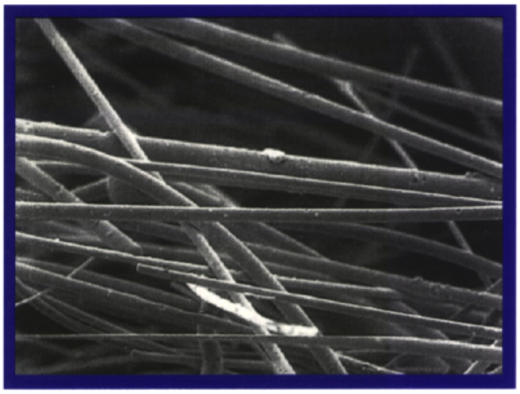

# Superconductor Structures

Neutron diffraction has proven to be a valuable technique for studying the atomic structure of high-temperature superconductors. This was demonstrated by scientists at Argonne National Laboratory's Intense Pulsed Neutron Source, who determined the structure shown here. Argonne is working with companies like DuPont and General Electric to understand how the materials work and how to make them better.



# Superconducting Filaments

Collaboration between Ames Laboratory and Babcock and Wilcox has led to a patent for a nozzle apparatus for making filaments of a high-temperature superconducting composite material that is ductile enough to use for wire conductors. Filaments of the superconductor are coated with silver, woven into yarn (shown on the right), compressed into a tape, and reacted at high temperature to form the composite.



# Measurement and Analysis

**... at the atomic level**

Advances in science are tied to the availability of state-of-the-art instrumentation and techniques for measurement and analysis. Inevitably this means that developing new measuring tools goes hand in hand with progress in the laboratory

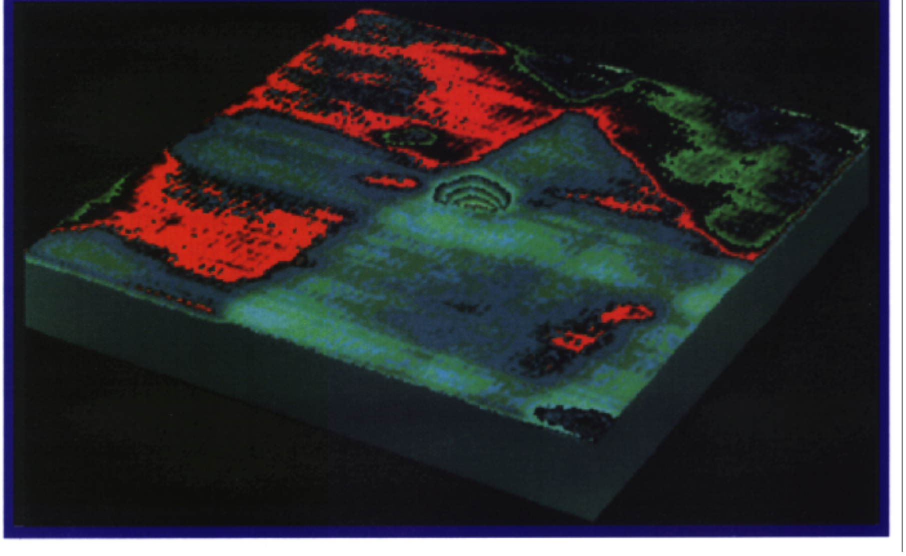
BES researchers are at the forefront when it comes to developing new instruments and techniques to identify and quantify atoms. This remains a key capability in an age when the purity and composition of materials are crucial to the success of manufacturing processes, from ultraminiaturized microelectronic chips to high-strength alloys. Equally critical is the ability to quantitatively identify chemical compounds.

Microscopes based on electrons or X-rays are part of the vanguard of analytical instrumentation, and BES and industry are working together to make full use of these vital capabilities. Some microscopes have such high magnification that researchers can see individual atoms, while others combine imaging with elemental and chemical analysis. Still others provide three-dimensional views of the interiors of otherwise opaque samples.

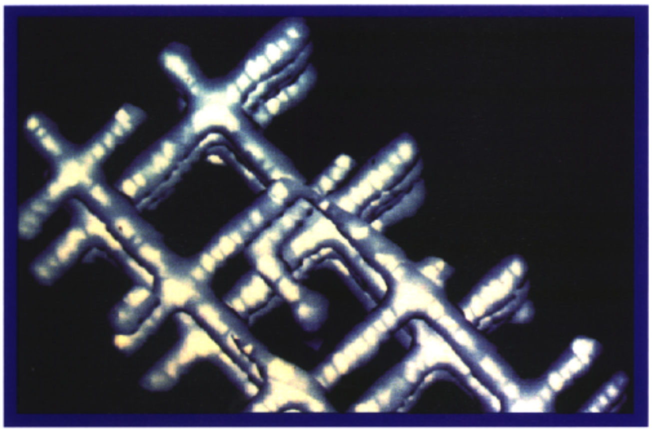
BES researchers are working closely with their counterparts in the private sector to expand the arsenal of tools available for measuring the physical, chemical, and biological attributes of matter. Whether semiconductor, superconductor, permanent magnet, laser, metal alloy, ceramic, polymer, or disease-fighting pharmaceutical, the fitness of the material for its intended purpose is determined through its properties.

In addition, the discovery of new materials is often made possible by correlating material properties with material functions. Combining materials theory with experiments helps researchers understand the material and develop the ability to predict its performance, and ultimately, it is hoped, to customize new materials with desired properties.

Instruments that can glimpse the intimate details of processes in real time (as they are happening) provide an essential tool for an enormous variety of needs, ranging from monitoring the quality of parts in a production line to investigating the progress of deterioration due to corrosion or other forms of degradation.



**The inter-facial force microscope allows researchers to create three-dimensional topographic images of surfaces without causing damage. This image, from an instrument developed under a cooperative research and development agreement among Sandia National Laboratories, Digital Instruments, Lucent Technologies, and the University of New Mexico, shows an indentation about 75 nanometers in diameter positioned near atomic crystal terrace steps on a gold surface.**

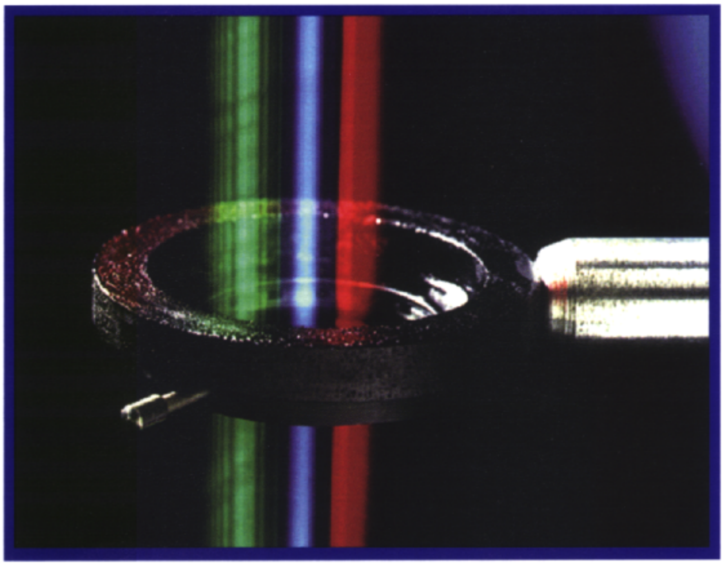


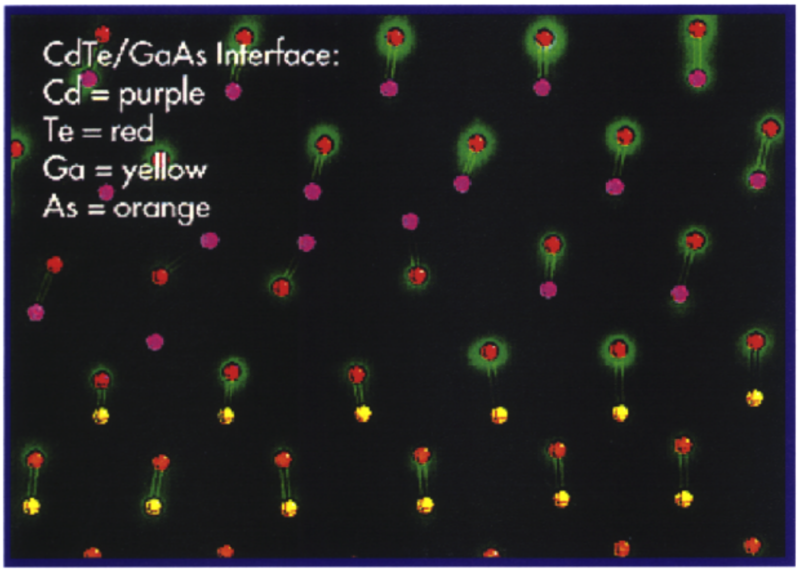
## Three-Dimensional Imaging

Scientists from IBM Research and Exxon Research and Engineering Co. are using X-rays from the National Synchrotron Light Source at Brookhaven National Laboratory to make three-dimensional images of the interior of complex electronic components (such as the internal wiring of the package on which computer chips are mounted shown here) and thereby test the effectiveness of manufacturing methods.

## Laser-Based Analysis

Scientists at Argonne National Laboratory have developed a sophisticated laser method, "Surface Analysis by Resonant Ionization of Sputtered Atoms" — SARISA, for short-to uniquely identify and accurately measure trace impurities in solid materials. SARISA uses up to three beams of different wavelengths (colors) to characterize the impurities. Together with scientists at SEMATECH, BES researchers demonstrated the effectiveness of this method for analyzing silicon wafers used in manufacturing computer chips






## Electron Microscopy

Z-contrast electron microscopy, a technique that uses new instrumentation developed jointly by VG Microscopes and the Oak Ridge National Laboratory, combines atomic resolution with elemental identification, as illustrated in this computer-enhanced image of the interface between two semiconductors, cadmium telluride and gallium arsenide. Winner of an R&D 100 award, this technique is now in use at several major laboratories.

# BES User Facilities

## ...a network of scientific resources

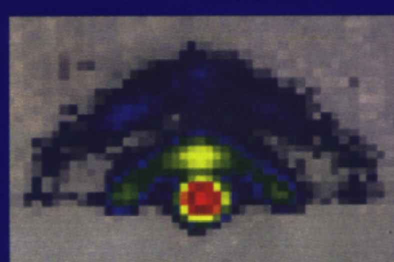
Today, the scientific establishment in the United States is a robust fabric of public and private research institutions, large national user facilities, and instrumentation located throughout the country. BES has a major responsibility for designing, constructing, and operating 17 of these complex scientific user facilities. Synchrotron light sources, high flux neutron sources, electron-beam microcharacterization centers, and other specialized facilities enable scientists to carry out experiments that could not be done in the laboratories of individuals. BES facilities are also key in developing next-generation instrumentation.

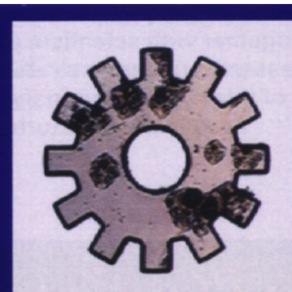
These facilities offer to outside researchers world-class capabilities for basic and applied research. The experiments conducted in BES user facilities embrace the full range of scientific and technological endeavors, including chemistry, physics, materials science, geology, environmental science, biology, biotechnology, and engineering science. The facilities offer a choice of methods for gathering information, ranging from structure at the atomic and molecular level to detailed maps of composition and chemical bonding — in short, all the features that determine the behavior of matter.

In a typical year, thousands of researchers and their students from academia, industry, and the federal laboratory system conduct research at these facilities. For approved experiments, operating time is available without charge to those scientists whose intent is to publish their results in the open literature. Proprietary research can also be accommodated on a full-cost-recovery basis. Over the past five years, the number of visitors using the facilities, including many from nations elsewhere around the globe, has grown more than threefold, especially evidenced in the increased number of industrial users.

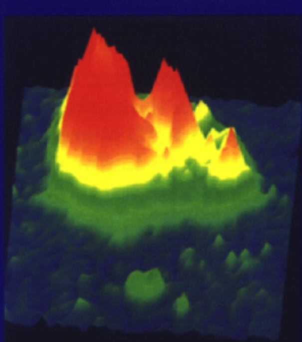
***Intense Pulsed Neutron Source***

**Complex fluids.** ***High Flux Isotope Reactor***



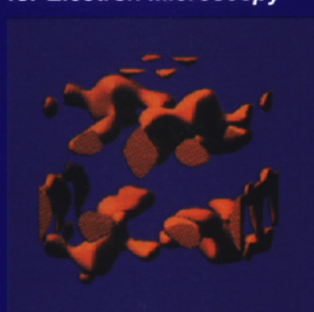


**Diamond gear.** ***Surface Modification and Characterization Facility***

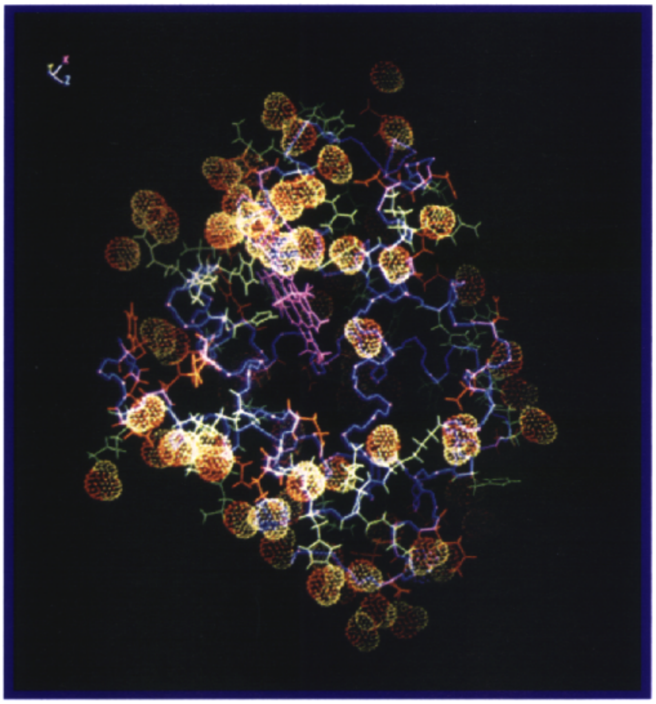


**Chromium particle.** ***Advanced Light Source***

**Atomic structure of staurolite.** ***National Center for Electron Microscopy***



***The Advanced Photon Source***



Skeletal model of myoglobin, a protein involved in respiration. *High Flux Beam Reactor*

# Neutron Sources

Neutrons have unique applications as probes in many scientific and technological fields. Neutron scattering has provided virtually all of the available information on the fundamental structure of the magnetic materials used in motors and generators, telecommunications, and video and audio technologies. Other applications of neutron scattering include biomolecular structure, polymer science, superconductivity, and the engineering properties of structural materials.

*High* Flux *Beam Reactor (HFBR), Brookhaven National Laboratory*

*High Flux Isotope Reactor (HFIR), Oak Ridge National Laboratory*

*intense Pulsed Neutron Source (IPNS), Argonne National Laboratory*

*Neutron Scattering Center(LANSCE), Los Alamos National Laboratory*

# Light Sources

Synchrotron light sources produce lightwaves (radiation) extending in the electromagnetic spectrum from infrared to X-rays. These beams of visible and invisible light enable researchers to probe, analyze, and image materials on a near-nanoscopic scale-including semiconductors, magnetic storage materials, composite materials, ceramics, polymers, pharmaceuticals, and biological molecules. Today, members from industry, academia, and the federal laboratories-and representing the materials sciences, physical and chemical sciences, geosciences, environmental sciences, biosciences, and medical and pharmaceutical sciences — use these synchrotron light sources to conduct state-of-the-art, cutting-edge research.

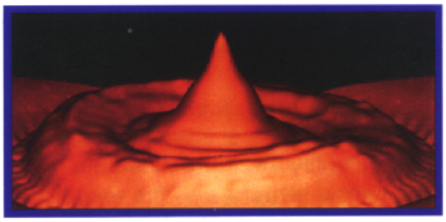
*Advanced Light Source (ALS), Lawrence Berkeley National Laboratory*

*Advanced Photon Source (APS), Argonne National Laboratory*

*National Synchrotron Light Source (NSLS), Brookhaven National Laboratory*

*Stanford Synchrotron Radiation Laboratory (SSRL)*

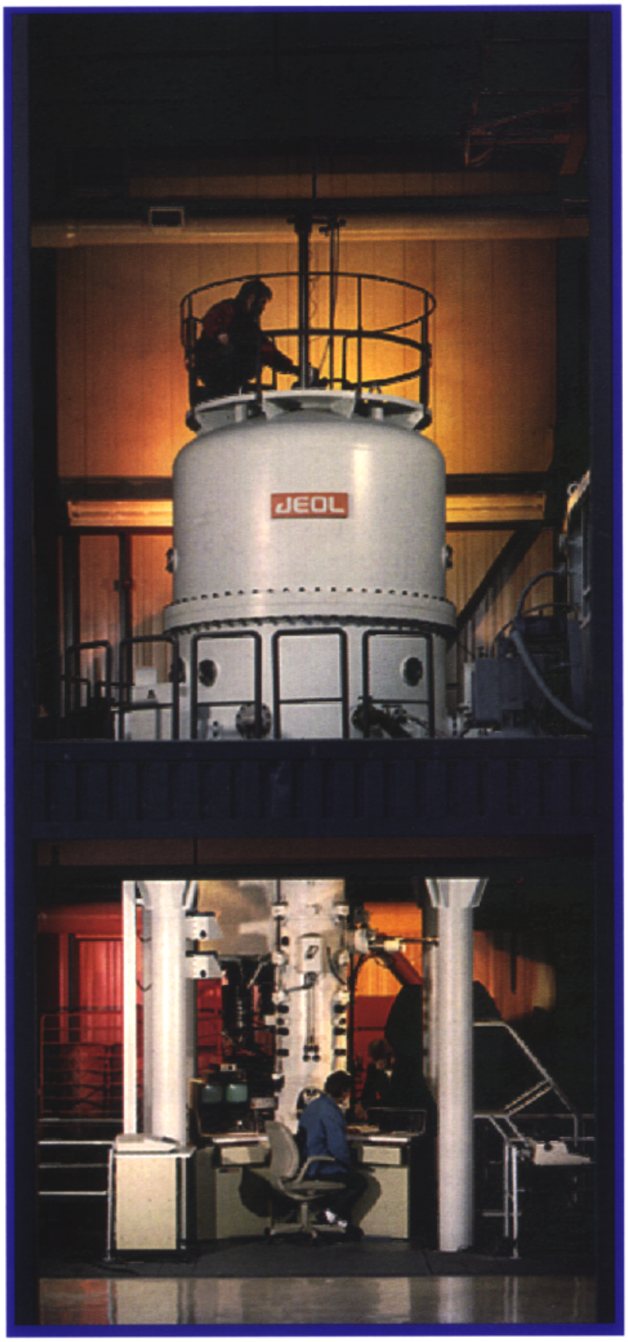
Miniaturized motors are created using deep-etch lithography, made possible by high-intensity X-rays. *Advanced Light Source, Lawrence Berkeley National Laboratory*

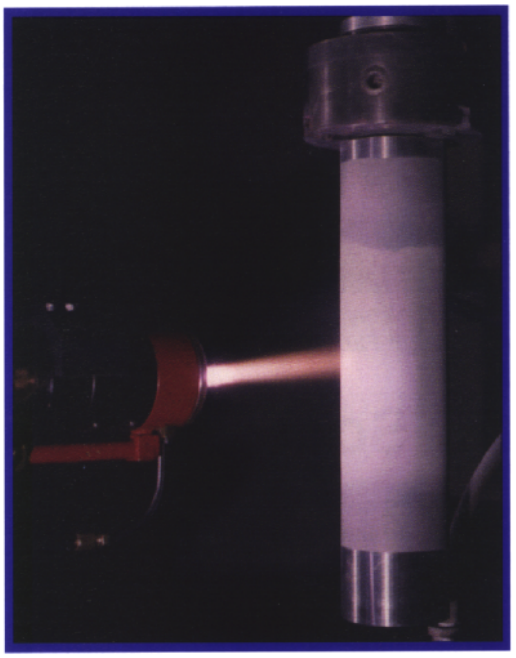


(left) A computer-enhanced pole-figure diagram of the X-ray diffraction from $CuInSe_2$. *Center for Microanalysis* of *Materials*

(below) Plasma arc spray coatings of quasicrystalline powders applied to metal surfaces improve wear and corrosion resistance. *Materials Preparation Center, Ames Laboratory, Iowa State University*

(below) The atomic resolution microscope. *National Center for Electron Microscopy at Lawrence Berkeley National Laboratory*



# Microcharacterization Centers

**BES electron-beam microcharacterization centers provide access to electron microscopes and other micro-analytical instruments and, thus, to unique capabilities for structural and chemical analyses.**

*Center for the Microanalysis of Materials (CMM), University of Illinois*

*Electron Microscopy Center, Argonne National Laboratory*

*National Center for Electron Microscopy (NCEM), Lawrence Berkeley National Laboratory*

*Shared Research Equipment Program (SHaRE), Oak Ridge National Laboratory*

# Other Facilities

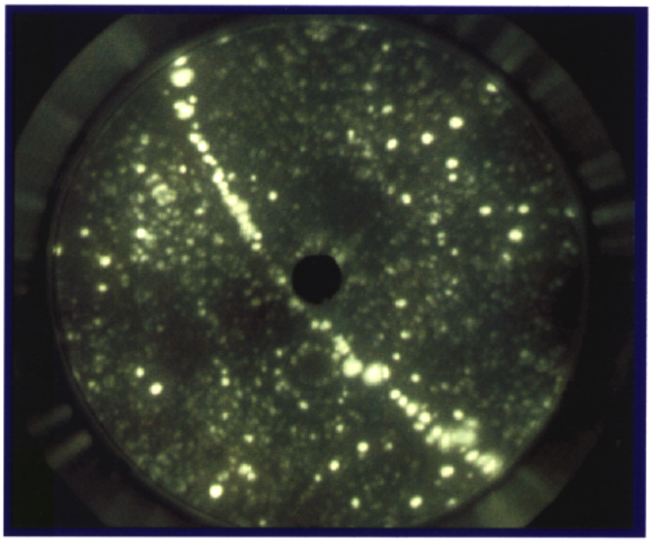
*Combustion Research Facility (CRF), Sandia National Laboratories*

*Materials Preparation Center (MPC), Ames Laboratory*

*Surface Modification and Characterization Research Center (SMAC), Oak Ridge National Laboratory*

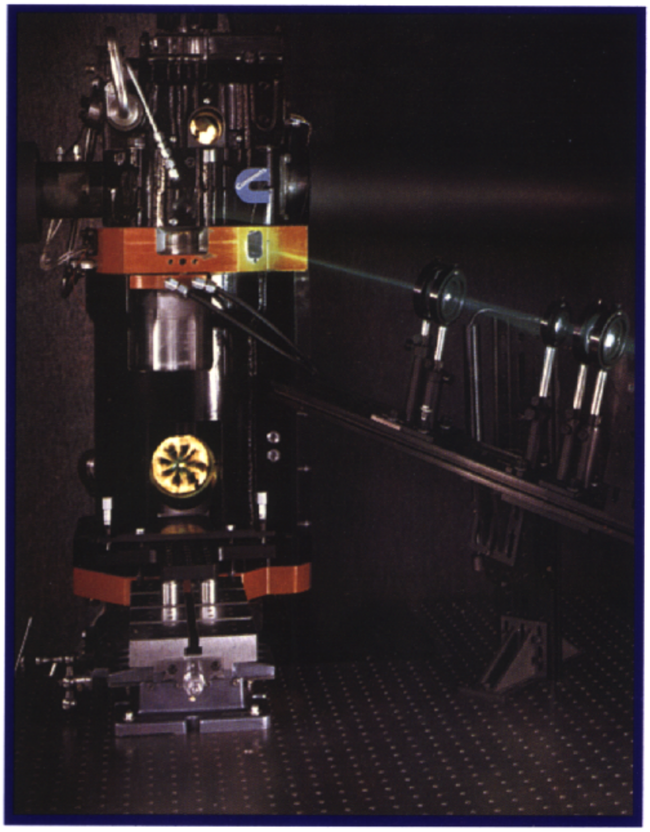
*Pulse Radiolysis Facility (PRF), Notre Dame University*

*James R. MacDonald Laboratory, Kansas State University*



**Grain boundary in a Babcock & Wilcox pressure vessel steel weld docorated with an ultrathin film of molybdenum-carbonitride precipitate (color-enhanced).** ***Shared Research Equipment Program (SHaRE), Oak Ridge National Laboratory***

**Lasers measure an operating diesel engine.** ***Combustion Research Facility, Sandia National Laboratories***



*Produced for the United States Department of Energy, Office of Energy Research, Office of Basic Energy Sciences, by Oak Ridge National Laboratory, Metals & Ceramics Division.*

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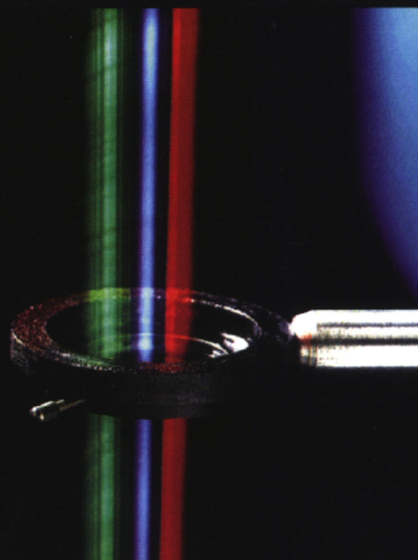

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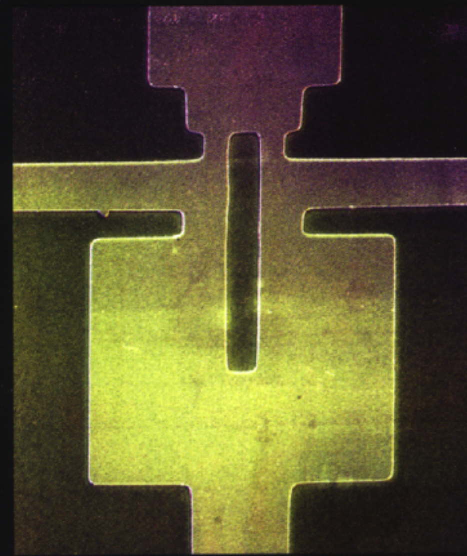

3M • ABB • ABC Laboratories • Accurate Automation • ACE Glass Company • Advanced Acoustic Concepts • Advanced Ceramics • Advanced Composite Materials • Advanced Micro Device • Advanced Refractory Technologies • Advanced Research Development • AGIP • Air Products and Chemicals • ALCAN Aluminum • ALCOA • Allegheny Ludnum • Allied-Signal • Alpha Metals • Altex Technologies • AMD • American Cyanamid • American Superconductor • Ametek • Amoco • Amorphous Technologies • Applicable Electronics • Applied Materials • ARCO Chemical • Armco • ASTeX • Astronautics Corporation • Atlas Wireline Services • AT&T • Avery-Dennison • Babcock & Wilcox • Baker Chemical • Basic Aircraft Research • BELLCORE • Bethlehem Steel • Bioanalytical Systems • BioCryst Pharmaceuticals • BioSym • Boeing • BP America • Bristol-Meyers Squibb • Bruker Instruments • Cabot Corporation • Calgon Vestal Labs • Carborundum • Cargill Incorporated • Carpenter Corporation • Caterpillar • Cemen Lining • Cercom • Chevron • Chromex • Chrysler Corporation • Clark Instrumentation • Coherent Corporation • Coloray Display • Combustion Engineering • Commercia Crystal Laboratories • COMSTOCK • Concrete Technology • Concurrent Technologies • Conductus • Cononco • Containerless Research • Continental Optical • Contro Vision International • Coolsounds • CoreTechs • Corning • Cray Research • CREE Research • Cryenco • Crystallume • CT Manufacturing • Cummins Engine • DEC • DFD Solid State Labs • Digital Instruments • Dionex • Doty Scientific • Dow Chemical • Dow Corning • Dupont • Dupont Merck • Dynamic Systems • Eagle-Pitcher • Eas Tennessee Radiometric Analytical Chemicals • Eastman Chemical U.S. • Eaton Corporation • EG&G • EiChroM Industries • Electric Power Research Institute • Electro Scientific Industries • Electronic Concepts • Elf-Aquitaine • Eli Lilly • Eltron Associates • EM Industries-OPTROX • EMCORE • Energy Conversion Devices • ERM Southwes • ESC Agentics • Etrema • Eveready Battery • Exxon • Exxon Production Research • Feher Research • Finnigan Corporation • Firestone • Fisons Instruments • Ford • FS International • Fulton Boiler Works • G&S Titanium • GAMS Development • Gas Research Institute • Gatan • Genetech • General Atomics Technology • General Electric • General Motors • Gillette • Glaxo • Glycomed • Golden Aluminum • Goodyear • Grumman Corporation • GTE • Halliburton Company • Harrison Alloys • Heller Environmen • Heraeus Corporation • Hercules • Hertel Cutting • Hewlett Packard • Hirsch Scientific • Hitachi America Limited • Hobart-TAFA • Hoechst Celanese • Hoffman LaRoche • Hoskins Manufacturing • Hughes Aircraft • IBIS Corporation • IBM • ICI • IGC/Advanced Superconductors • IGRDM • II-IV/eV Products • IKU • Illinois Superconductor • Implant Sciences • Inland Motors • Inland Steel Industries • INRAD • Intel • Intermagnetics General • Intevep S.A. • IonSpec • IonWerks • ISM Technologies • J A Woollam • JEOL USA • JNOC • Jobin-Yvon • John Deere • Johnson Manufacturing • Kairos • Kennametal • Keramount • Kinetic Systems • Kodak • Komag Corporation • Komwave • Kopin Corporation • Lachat Instruments • Lake Shore Cryotronics • Lam Research • Lambda Research • Lambda Technologies • Lamson and Sessions • Lederle Laborator • Lennox Industries • Lewis Corporation • Lightning Optical • Lightwave Electronics • Litton-Airton • Lockheed Martin • LTV Steel • Lucent Technologies • M. W. Kellogg • Magnetics International • Marathon Oil • Marlow Industries • Masonite • MathWorks • McDonnel Douglas • MEMC Electronic Materials • Mer Corporation • Merck an Company • Metallamics • Microscience • Miles • Mitre Corporation • Mobil • Mobil Research and Development • Model Environmental Corporation • Molecular Design • Molecular Structure • Molecular Tool • Moltech Corporation • Monsanto • Morgan Construction • Morton Advanced Materials • MOSET • Motorola • Nalco Chem. Co. • Nan Instruments • Nanophase Technologies • National Center for Manufacturing Sciences • National Steel • National Tank Company • Navistar Int. • nCube • NEC USA • Nomadi Technologies • Norsk Hydro • Northrup • Norton Diamond Film • Ohio Brass • Ontario Hydro • ORDELA • ORION-Advanced Chemicals Technology • Otsuka America • Ovonic Synthetic Materials • Oxford Instruments • Oxford Superconducting • Pathway Bellows • Pennzoil • Petrolite • Pfizer • Phase Metrics • Phillips Electronics • Phillip Petroleum • Photocatalytics • Photon Sciences International • Phytogen • Pioneer Hi-Bred International • Plasma Physics • Plasmaquest • Positive Light • PPG Industries • PracSys • Pratt and Whitney • Proctor and Gamble • QMAX • Quadra Logic Technologies • Quantronix • Quantum Design • Radiant Technologies • Radio Logic • Rapi Technologies • Raychem • REMOTEC • Reynolds Metal Company • RHK Technologies • Rhone-Poulenc • RIBTEC • RKK • Rocketdyne Division • Rockwell International • Rohm & Haas • Rohr Industries • Rouge Steel • Rudolph Research • Sage Petroleum • Sauer-Sunstrand • Schlumberger-Doll • Science Applications International • Scienc Research Laboratory • Science Wares • SCM Metals • Seagate Technologies • Seattle Specialty Ceramics • Sematech • Semitherm • SGV Thermco • Shell Oil • Si Richardson Carbon Company • Signetics • Silicon Video • Smith and Nephew Richards • SmithKline Beecham • Solar Kinetics • Sonics and Materials • Sony • SOPRA • South Bay Technology • SPAR Aerospace • Spectrolab • Spire Corporation • State Industries • Statoil North America • Stepan Inc. • Sterling Withrop • STI Optronics • Strategene • Supelco • Supercon • Superconductive Company • Superconductor Technology • Superior Vacuum Technology • SVT Associates • Sylvania • Syntex USA • T-Y-Lin International • Taber Metals • Tate Industries • TDA Research • Tektronics • Teledyne • Teledyne - Wah Chang • Texaco • Texaco E&P Technologies • Texa Instruments • Thinking Machine Corporation • Tienzyme • TiNi Alloy Corporation • Titan • TN Technologies • Torrington • Tri-Mark Metals • Ultramet Corporation • Ultrathern • Union Carbide • United Technologies • Universal Energy Systems • Unocal • UOP • Upjohn • USCAR • Valenite Corporation • Vapex Environmental Technologies • W. R. Grace • Western Atlas International • Westinghouse Electric • X-Ray Instrumentation Associates • Xerox • Xsirius Superconductivit