# Advancing Scientific Understanding

***Science Strategic Goal:*** *To protect our national and economic security by providing world-class scientific research capacity and advancing scientific knowledge.*

*"Scientific and technological research are a high calling for any individual. And promoting research is an important role of our Federal government. . . . We'll continue to support science and technology because innovation makes America stronger. Innovation helps Americans to live longer, healthier, and happier lives. Innovation helps our economy grow, and helps people find work. Innovation strengthens our national defense and our homeland security. . . ."*

***President George W. Bush***

Basic scientific research in the physical sciences is one of the foundations for economic growth and national security in this country. Achievements and benefits in areas such as public health, telecommunications, and supercomputing are dependent upon progress in the physical sciences. The Department's Office of Science (SC) is a primary government sponsor of basic scientific research in the U.S., and leads the Nation in supporting the physical sciences in a broad array of research subjects in order to improve our Nation's energy security, and to address issues ancillary to energy, such as climate change, genomics, and life sciences.

An important component of the Department's science activities is its operation and management of 10 national laboratories and 27 scientific user facilities, including x-ray and optical light sources, supercomputers, fusion devices, and particle accelerators across the country. The suite of user facilities plays a vital role in the Nation's science and technology portfolio, annually drawing over 17,000 users from universities, industry, and government.

The President's affirmation of the importance of Federal investments in science and technology continues an unbroken line of support by our Nation's leaders for the sciences that stretches back over 50 years – a line of support that parallels the history of the Office of Science and its predecessors.

The following section contains an overview of the results associated with the performance against the most significant goals and annual targets for FY 2004.

# Science General Goal

## Performance Scorecard:

**SCIENCE** ($ in Millions)

| GENERAL GOAL | FY04 PROGRAM COST | FY03 PROGRAM COST | PROGRAM GOALS | *FY 2004 Budgetary Expenditures Incurred | OVERALL PROGRAM SCORE | PERFORMANCE OF ANNUAL TARGETS | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | MET | NOT MET (≥80%) | NOT MET (<80%) | UNDETERMINED |
| World-Class Scientific Research Capacity | $3,196 | $3,068 | High Energy Physics | $796 | | 4 | 0 | 0 | |
| | | | Nuclear Physics | $420 | | 4 | 0 | 0 | |
| | | | Bio and Environmental Research | $598 | | 5 | 0 | 0 | |
| | | | Basic Energy Sciences | $1,128 | | 5 | 0 | 0 | |
| | | | Advanced Scientific Computing Research | $210 | | 2 | 0 | 1 | |
| | | | Fusion Energy Sciences | $276 | | 2 | 0 | 0 | |
| Total Costs | $3,196 | $3,068 | | $3,428 | | 22 | 0 | 1 | 0 |

*Includes capital expenditures but excludes such items as depreciation, changes in unfunded liability estimates and certain other non-fund costs, and allocations of Departmental administration activities.

## *World-Class Scientific Research Capacity – General Goal 5:*

**Provide world-class scientific research capacity needed to: ensure the success of Department missions in national and energy security; to advance the frontiers of knowledge in physical sciences and areas of biological, medical, environmental, and computational sciences; or provide world-class research facilities for the Nation's science enterprise.**

The common thread woven throughout all of the Department's activities is science – basic research underpins the Department's applied technology programs through strategic investments that fuel discoveries in materials sciences, chemistry, plasma science, plant sciences, biology, computation and environmental studies. SC plays five key roles in the U.S. research enterprise:

- Supports the missions of the Department, delivering the scientific knowledge for solutions to our Nation's most critical energy and environmental challenges;
- Acts as the Nation's leading supporter of the physical sciences, including physics, chemistry and materials science;
- Maintains stewardship of world-class scientific tools, building and operating major research facilities for use by the world's scientific community;
- Serves as a key Federal agency for the creation of leadership class computational facilities for open science, enabling solutions to problems in science and industry not attainable by simple extrapolation of existing architectures; and
- Supports a diverse set of researchers, including those at more than 280 universities in every state in the Nation as well as scientists and technicians at the Department's national laboratories and in industry.

### *External Factors*

The following external factors could affect our ability to achieve this goal:

- **Scientific and Technical Talent**: The prospect of insufficient scientific and technical talent, now and in the foreseeable future, threatens our ability to maintain world-class scientific capacity.
- **National Support for Science**: Eroding national support for investments in the physical sciences that provide the critical foundations to virtually all other fields of science, and the rapidly growing dependency between the biological and physical sciences.

### *How We Serve the Public*

The investments in the most basic areas of research spark our imaginations and advance our human curiosity about the universe in which we live. Historically, these investments have also paid handsome dividends in terms of new technologies that have raised our standard of living and even extended our life expectancy. For instance, the youngest school child thinks nothing of working on a personal computer, which is based upon state-of-the-art electronics. Life-threatening ailments are imaged, diagnosed, and treated without ever having to resort to surgery. And people can speak clearly to others halfway around the world using a phone barely the size of a human hand. Hopefully, our current efforts supporting the development of an artificial retina will help some blind people see.

It is also interesting to note that many of the great scientific advances of the last century resulted from experiments that yielded results that were completely different from what theory had predicted. Today, those successful "failures" have led to a new understanding of the microscopic structure of matter and to the technology so essential to modern life.

## *Program Goals and Targets Supporting World-Class Scientific Research Capacity*

**High Energy Physics (HEP):** Understand the unification of fundamental particles and forces and the mysterious forms of unseen energy and matter that dominate the universe; search for possible new dimensions of space; and investigate the nature of time itself (SC GG 5.19). This program goal supports the General Goal by advancing the frontiers of knowledge in the physical sciences.

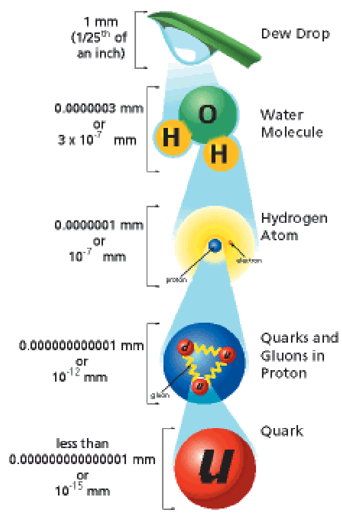
We have learned much about the universe we exist in (see insert to the right). Nevertheless, we are continually humbled by what we still do not understand. Key scientific questions that are now being asked about the universe at its two extremes – the very large and the very small – are inextricably intertwined:

- Can we realize Einstein's dream – a unified description of fundamental particles and forces in the universe?
- Where is the fundamental particle that endows all other particles with their masses?
- Are there additional or "hidden" dimensions of space-time?
- What are the masses of the neutrinos, and what is their role in the universe?
- Why is there more matter than anti-matter in the universe?
- What are dark matter and the dark energy, which together make up more than 95 percent of the universe?

How the universe originated – its genesis – is one of the great mysteries of science. The HEP program explores and discovers the laws of nature as they apply to the basic constituents of matter, and the forces between them.

The following key annual targets represent experiments at HEP accelerators seeking evidence for unification: the blending of today's diverse patterns of particles and interactions into a much simpler picture at high particle energies, like those that prevailed in the very early universe.

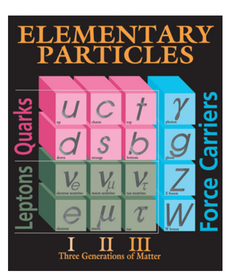
**The Building Blocks of a Dew Drop and The Standard Model: Quarks, Leptons, and Bosons**




*A dew drop is made up of many molecules of water ($10^{21}$ or a billion trillion). Each molecule is made of an oxygen atom and two hydrogen atoms ($H_2O$). At the start of the 20th century, atoms were the smallest known building blocks of matter.*

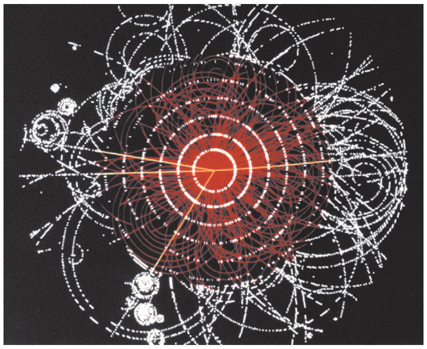
*Each atom consists of a nucleus surrounded by electrons. Electrons are leptons that are bound to the nucleus by photons, which are bosons. The nucleus of a hydrogen atom is just a single proton. Protons consist of three quarks. In the proton, gluons hold the quarks together just as photons hold the electron to the nucleus in the atom. Physicists call the theoretical framework that describes the interactions between elementary building blocks (quarks and leptons) and the force carriers (bosons) the Standard Model.*

**The Standard Model:**




*Physicists currently believe there are three types of basic building blocks of matter: quarks, leptons, and bosons. Quarks and leptons make up everyday matter, which is held together by bosons. Each boson is associated with a force. The photon, the unit of the electromagnetic force, holds the electron to the nucleus in the atom. The way these particles combine dictates the structure of matter.*

**Proving the Existence of the Higgs Field by Finding the Higgs Boson**



*A computer simulation depicts the decay of a Higgs boson, which is believed to give mass to elementary particles, into four muons.*

*As people float in water they "become" lighter. Depending on size, shape, etc, some people float better than others. The proposed Higgs field concept could be thought of as the opposite of people swimming in water. Every particle in our universe "swims" through the Higgs field, which is the "stuff" that gives all other particles a mass. Different particles interact with the Higgs field with different strengths, hence some particles are heavier (have a larger mass) than others. (Some particles have no mass. They don't interact with the Higgs field – they don't feel the field.) Unfortunately, we cannot directly probe for the Higgs field.*

*The proposed Higgs boson is a particle. It gets its mass like all other particles – by interacting with ("swimming in") the Higgs field. It can be thought of a dense spot in the Higgs field, which can travel like any other particle – like a drop of water in water vapor.*

*Though the Higgs particle interacts with all massive particles it prefers to interact with the heaviest elementary particles we know, especially the top quark. Because of this property of the Higgs boson, physicists have a chance to find evidence for the Higgs boson itself. As the mediating particle of the proposed Higgs field, discovering the Higgs boson would demonstrate the existence of the Higgs field.*

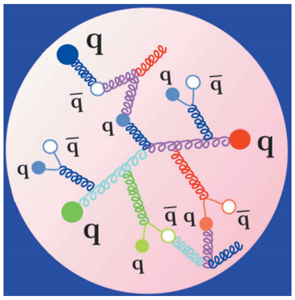
*Discovery of the Higgs boson has the potential to profoundly affect our understanding of the universe. Likewise if the Higgs boson were found not to exist, it would be a major blow to the Standard Model.*

- The search for evidence of a simpler, unified picture of the universe was the primary emphasis at Fermi National Accelerator Laboratory (FNAL). In 2004, FNAL operated the Tevatron accelerator and associated detectors for 36 weeks at higher data rates in its search for the "fingerprints" of unification – such as the Higgs boson, the expected source of mass (see insert above). The higher data rate achieved, measured by increased luminosity (331 inverse picobarnes exceeded the target goal of 192 inverse picobarnes), enhanced researchers' ability to make precise measurements and discover new phenomena (SC GG 5.19.1).
- Current theory speculates that very early in the evolution of the universe, the initial quantities of matter and anti-matter became lopsided, or "asymmetrical," resulting in the matter-based universe we now know. By measuring the matter- antimatter asymmetry in particle interactions (known as Charge-Parity, or CP, violations), physicists hope to understand one of the world's most mysterious phenomena – why, in the moments after the Big Bang, matter and antimatter did not annihilate one another and leave the cosmos empty. Observing this small imbalance in elementary particle interactions was the focus of the 39 weeks of operations at the Stanford Linear Accelerator Center in 2004. The higher data rate achieved, measured by increased luminosity (117 inverse femtobarnes exceeded the target goal of 45 inverse femtobarnes), enhanced researchers' ability to analyze data for examples of CP violation (SC GG 5.19.2).

**NUCLEAR PHYSICS (NP)**: Understand the evolution and structure of nuclear matter, from the smallest building blocks (quarks and gluons), to the elements in the Universe created by stars; to unique isotopes created in the laboratory that exist at the limits of stability and possess radically different properties from known matter (SC GG 5.20). This program goal contributes to the General Goal by advancing the frontiers of knowledge in the physical sciences.

Protons and neutrons (nucleons) were born in the first minutes after the Big Bang. Their subsequent synthesis into the elements (nuclei) goes on in the ever-continuing process of nuclear synthesis in stars and supernovae. Nuclear matter is the "stuff" that makes up our planet and its inhabitants.

Today, understanding nuclear matter and its interactions has become central to research in nuclear physics and important to research in energy, astrophysics, and national security. For example, the development of Quantum Chromodynamics – QCD (see insert on the following page), has provided a method to quantitatively describe nuclear matter in terms of its underlying fundamental quark and gluon constituents. We have only recently acquired more sensitive tools to make the



*The strong nuclear force is responsible for binding quarks together to form protons and neutrons, and the residual effects also bind these neutrons and protons together in the nucleus of the atom.*

*According to Quantum Chromodynamics (QCD), every quark carries color charge which comes in three types: "red", "green" and "blue" (see the figure). These are just names and not related to ordinary colors in any way. Antiquarks are either "anti-red", "anti-green" or "anti-blue." Like colors repel, unlike colors attract. The attraction between a color and its anti-color is especially strong.*

*The strong interaction acts between two quarks by exchanging particles called gluons. The strong interaction has a very limited range – not much farther than the radius of a proton. It also has a strange effect – as the distance between two quarks increases, the amount of energy in the force between them increases. If the force becomes strong enough, there is enough energy to create new quarks.*

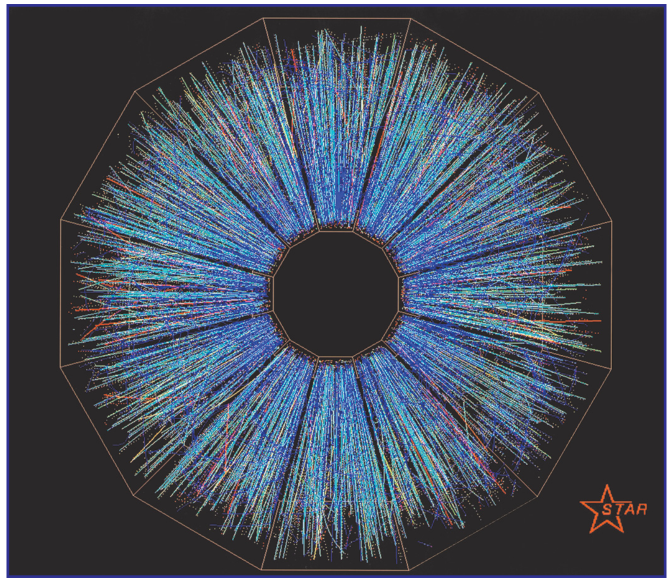
*The textbook allegory is that of a rubber band. When the rubber band is stretched far enough, the band breaks and you have two new rubber bands. Similar with quarks: separate the quark pair far enough, and two new quarks will pop up.*

measurements and calculations needed to address the key questions of modern Nuclear Physics:

- What is the structure of the nucleon?
- What is the structure of nucleonic matter?
- What are the properties of hot nuclear matter?
- What is the nuclear microphysics of the universe?
- What is to be the new Standard Model?

Understanding how nuclear matter is formed is critical to understanding the processes within stars and how elements are created – including possible new states of matter and elements – at high-energy densities and the extreme limits of stability. The NP program explores the extremes of nuclear matter and the processes that form all the chemical elements in stars and supernovae.

In 2004, the target number of events for accelerator experiments was met or exceeded at the following facilities: the Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility in Newport News, Virginia; the Relativistic Heavy Ion Collider (RHIC) at

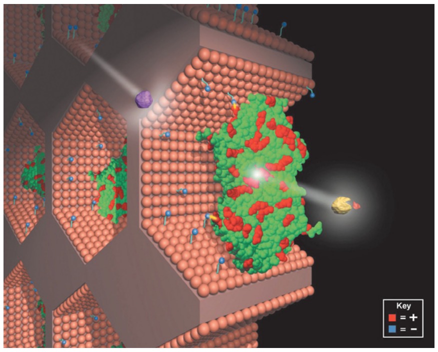



*End view of a collision of gold beams in STAR detector at BNL's Relativistic Heavy Ion Collider (RHIC).*

Brookhaven National Laboratory (BNL) in New York (see above insert); the Argonne Tandem Linac Accelerator System (ATLAS) at Argonne National Laboratory (ANL) in Illinois; and the Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory (ORNL) in Tennessee (SC GG 5.20.2 and SC GG 5.20.3).

**BIOLOGICAL AND ENVIRONMENTAL RESEARCH (BER):** Provide the biological and environmental discoveries necessary to clean and protect our environment, offer new energy alternatives, and fundamentally alter the future of medical care and human health (SC GG 5.21).

BER is key to General Goal 5 in that it advances environmental and biomedical knowledge that promotes national security, and potentially has broad impacts on our health, our environment, and our energy future. For example, microbes are among Nature's most underappreciated resources. They thrive in extreme environments. They consider toxic waste a gourmet meal, and some are mini-factories that can produce energy supplies. A BER challenge is to learn how to get microbes to work for us, to turn microbes into mighty engines of scientific progress. BER uses the knowledge and tools that we have developed over the past two decades of research into genomics to understand how microbes may be able to clean up chemical and radioactive pollutants and to produce abundant and clean energy. The following key

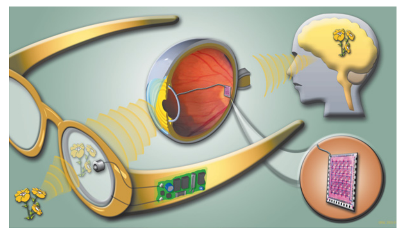



*Learning about the inner workings of microbes and their diverse inventory of molecular machines can lead to the discovery of ways to isolate and use these components to develop synthetic nanostructures that carry out some of the functions of living cells. In this figure, the enzyme organophosphorus hydrolase (OPH) has been embedded in a synthetic nonomembrane (mesoporous silica) that enhances its activity and stability [J. Am. Chem.Soc. 124,11242-43 (2002)]. The OPH transforms toxic substances (purple molecule at left of OPH) to harmless by-products (yellow and red molecules at right). Applications such as this could enable development of efficient enzyme-based ways to produce energy, remove or inactivate contaminants, and sequester carbon to mitigate global climate change. The knowledge gained from DOE genomics research also could be highly useful in food processing, pharmaceuticals, separation, and the production of industrial chemicals.*

annual targets have directly contributed to the BER program goal.

- We currently know very little about most microbial communities, including the microbes they are made of, the biochemical capabilities of those communities, and the regulatory mechanisms for those capabilities (see above insert). The Life Sciences sub-program focused on microbial research – looking at the most basic molecular-level process of nature – which offers tremendous promise for a safer, stronger, healthier and more secure world. Increasing the rate of Deoxyribonucleic Acid (DNA) sequencing (SC GG 5.21.2) increases the available source of "raw data" needed to carry out research in this area.
- Advanced climate models are needed to describe and predict the roles of oceans, the atmosphere, sea ice and land masses on climate. So too, the role of clouds in controlling solar and terrestrial radiation onto and away from the Earth needs to be better understood since it is the largest uncertainty in climate prediction. The Climate Change Research sub-program continued its efforts in the development of improved methods of climate data collection, and improved model-based climate prediction capability, thereby achieving the annual target (SC GG 5.21.3). Advancing our understanding of global climate change and our ability to predict climate over decades to centuries is critical to enable us to develop science-based solutions to minimize the impacts of climate change and to better plan for our Nation's future energy needs.

**How Does the Artificial Retina Work?**



*The implant has pieces both inside and outside the eye. Patients wear glasses, like those shown on the left, with a tiny camera embedded in the lens. The camera captures images and sends the data to a microprocessor (concealed in the side of the glasses) which converts the data to an electronic signal. An antenna in the lens transmits the signal to a receiving antenna in the eye. The signal then travels along a tiny wire to the retinal implant. The signal causes the implant to stimulate the remaining retinal cells which send the image along the optic nerve to the brain.*

- Developments in imaging technology have the potential to revolutionize all of medical imaging with increases in sensitivity, ease of use, and patient comfort. Technological wonders are on the horizon, like an artificial retina (see above insert) that is being developed by a multidisciplinary team of scientists within the Department. The artificial retina can help patients with muscular degeneration and retinitis pigmentosa regain useful eyesight. In 2004, a 60 microelectrode array was fabricated for use as an artificial retina, and planned animal testing completed, thereby achieving the annual target (SC GG 5.21.5).

**BASIC ENERGY SCIENCES (BES):** Provide the scientific knowledge and tools to achieve energy independence, securing U.S. leadership and essential breakthroughs in basic energy sciences (SC GG 5.22).

Nanoscale science research – the study of matter at the atomic scale – is taking us into a realm where the properties of materials are dramatically different from what we have today. Structures composed of just a few atoms and molecules may be engineered to assemble themselves into useful devices such as computers that can store trillions of bits of information on a device no larger than the head of a pin or implantable in diagnostic monitors the size of a cell. Large and complicated structures will be designed, one atom at a time, for desired characteristics such as super-lightweight and ultra-strong materials. BES is helping to lead this revolution and advance the progress of General Goal 5 by advancing the frontiers of knowledge in the physical sciences associated with nanoscale research in materials sciences, physics, chemistry, biology, and engineering, and developing the tools that can probe and manipulate matter at the atomic scale.

Research at the nanoscale is critical to revolutionary advances in materials properties and behaviors. Four thrust areas have been identified in this area: (1) attain a fundamental scientific understanding of nanoscale phenomena, particularly collective phenomena; (2) achieve the ability to design and synthesize materials at the atomic level to produce materials with desired properties and functions; (3) take full advantage of major user facilities, and (4) develop experimental characterization techniques and theory/modeling/simulation tools necessary to drive the nanoscale revolution. The following key annual targets have contributed toward achieving the BES program goal:

*Seeing things tiny has been a long quest, one that predates our knowledge of the existence of atoms. The visible light microscope, invented about four hundred years ago and based on optics studies dating back one thousand years, gave us an initial glimpse of Nature's assemblies; however, fundamental laws of physics limit their resolution. The typical size of an atom is tenths of a nanometer, and the laws of physics limit the resolution (i.e., the smallest features that can be seen) of visible light microscopes to features roughly a few hundred nanometers in size. Thus, instruments with resolutions one thousand times better than the best visible light microscopes are required to see atoms.*

*To see atoms, we must use probes that are themselves as small as the atoms under investigation. Three such probes are: x-rays, electrons, and neutrons. Each has become the basis for major scientific user facilities in materials research and related disciplines. The BES synchrotron radiation light sources (such as the pictures photon source at Argonne National Laboratory), electron-beam microcharacterization centers, and neutron scattering facilities are revealing the atomic world.*

- Our ability to conduct research at the nanoscale depends on our ability to observe, characterize, manipulate, and computationally model matter at the atomic or molecular scale (see insert to the right). This is a fundamentally interdisciplinary effort, linking science and engineering, and providing the foundation for a broad spectrum of scientific and technical advances. Essential tools for this research include current generation synchrotron x-ray and neutron scattering sources, and the more advanced sources to come, higher resolution electron microscopes and other atomic probes, and terascale computers which are capable of 'seeing' very small (SC GG 5.22.1) items that behave in a very fast (SC GG 5.22.2) manner. In FY 2004, targets addressing these areas were met.
- A primary focus of the BES program is continued support of nine scientific user facilities at near maximum operating levels (SC GG 5.22.5), and the design, fabrication, and construction of new facilities within established cost and schedule baselines to characterize and ultimately control materials (see the following NSRC insert) (SC GG 5.22.4). In FY 2004, both of these targets were achieved.

**ADVANCED SCIENTIFIC COMPUTING RESEARCH (ASCR):** Deliver forefront computational and networking capabilities to scientists

## National Science Research Centers

Center for Functional Nanomaterials at Brookhaven National Laboratory

Center for Nanophase Materials Sciences at Oak Ridge National Laboratory

Molecular Foundry at Lawrence Berkeley National Laboratory

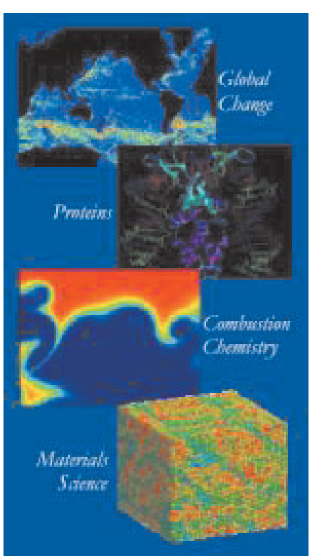
Center for Nanoscale Materials at Argonne National Laboratory

Center for Integrated Nanotechnologies at Sandia National Laboratories & Los Alamos National Laboratory

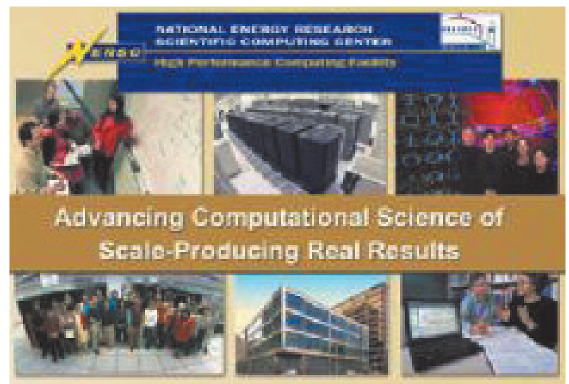
*The Nanoscale Science Research Centers (NSRCs) supported by Basic Energy Sciences will be research facilities for the synthesis, processing, and fabrication of nanoscale materials. They will be collocated with existing user facilities to provide sophisticated characterization and analysis capabilities. In addition, NSRCs will provide specialized equipment and support staff not readily available to the research community. NSRCs will be operated as user facilities and be available to all researchers.*

nationwide that enable them to extend the frontiers of science, answering critical questions that range from the function of living cells to the power of fusion energy (SC GG 5.23).

Computer-based simulation enables us to model the behavior of complex systems that are beyond the reach of our most powerful experimental probes or our most sophisticated theories. Computational modeling has greatly advanced our understanding of fundamental processes of nature, such as fluid flow and turbulence or molecular structure and reactivity. Advancing scientific computing supports the Science General Goal of providing world-class scientific research capacity since advanced scientific computing has become a true third pillar of discovery – joining theory and experiment as a standard tool that researchers now rely upon to make scientific progress.




*Computational science capabilities already underpin the research and development that the Department conducts to meet its energy and national security missions. Because these capabilities are central to our missions, and because computational capability is also so critical to scientific discovery generally, it is appropriate that the Office of Science brings a renewed focus to this challenge.*




***The National Energy Research Scientific Computing (NERSC) Center****, managed and operated by Lawrence Berkeley National Laboratory, is a world leader in accelerating scientific discovery through computation.*

A principle responsibility of ASCR is to provide the high-performance computational and networking resources that are required for world leadership in science (see above insert). Activities in FY 2004 that supported this effort can be divided into two areas:

- 'Near Term Results' are activities represented by efforts to focus on scientific problems which can simultaneously use the large numbers of computer processors that are currently available from the massively parallel processor high performance computing systems. One of these activities was the NERSC initiative to ensure that 50 percent of the scientific computing runs use more than 512 processors (SC GG 5.23.2). A number of critical computationally intensive, large-scale research projects, such as global climate, could not make effective use of 512 or more processors during most of FY 2004. In June 2004, ASCR began charging for only 50% of the hours used for large scale projects as an incentive to attract researchers. This action lead to 66% of the NERSC usage during the fourth quarter of FY 2004 being for large scale projects. However, the overall result of 47% was not enough to achieve the annual target.

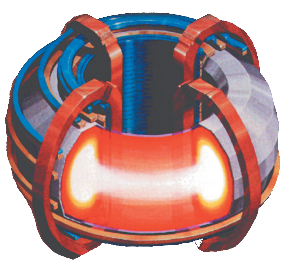
- 'Longer term result' activities are a part of the Next Generation Computer Architecture (NGA) effort to identify and address major bottlenecks in the performance of existing and planned Departmental science applications.

**FUSION ENERGY SCIENCES (FES):** Answer the key scientific questions and overcome enormous technical challenges to harness the power that fuels a star (SC GG 5.24).

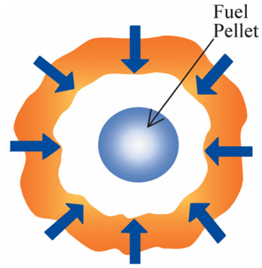
Our challenge in supporting General Goal 5 is to provide the national basic research effort to advance plasma science, fusion science, and fusion technology – the knowledge base needed for an economically and environmentally attractive fusion energy source.

***Magnetic and Inertial Confinement***

*The two principal approaches for confining fusion fuel on earth are magnetic and inertial. Magnetic fusion relies on magnetic forces to confine the charged particles of the hot plasma fuel for sustained periods of fusion energy production. Inertial fusion relies on intense lasers or particle beams to rapidly compress a pellet of fuel to the point where fusion occurs, yielding a burst of energy that would be repeated to produce sustained energy production.*



*Magnetic*

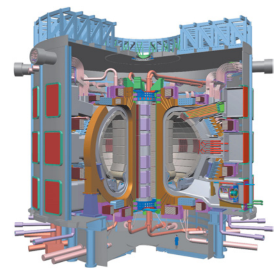



*Inertial*

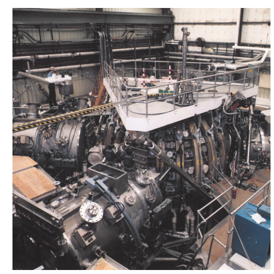
Fusion is the energy process that powers the stars. Fusion energy science studies the fundamental processes taking place in plasmas where the temperature and density approach the conditions needed to allow the nuclei of low-mass elements such as hydrogen and isotopes to join together, or fuse, giving off tremendous amounts of energy. Power generated from fusion energy produces no troublesome emissions, is safe, and has few, if any, proliferation concerns. It creates no long-lived waste and runs on fuel readily available to all nations.

## Major Collaborative Facilities

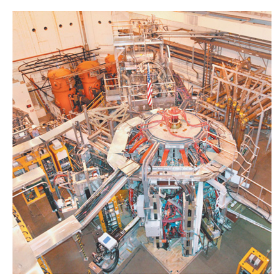
***The Future: ITER.*** *The US is engaging in negotiations with international partners aimed at constructing the world's first sustained burning plasma experiment, capable of producing 500 million watts of fusion power for periods of 5 minutes or more.*



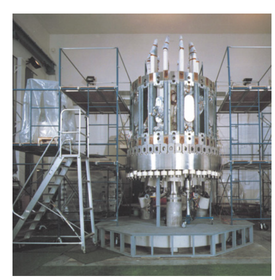
***DIII-D,General Atomics,*** *is the largest magnetic fusion research facility in the United States, with plasmas at close to fusion reactor temperatures.*



***NSTX, Princeton Plasma Physics Laboratory,*** *is an innovative magnetic fusion device that was constructed by the Princeton Plasma Physics Laboratory in collaboration with the Oak Ridge National Laboratory, Columbia University, and the University of Washington, Seattle.*



***Alcator-C-Mod, Massachusetts Institute of Technology,*** *is a unique, compact-tokamak facility that uses intense magnetic fields to confine high-temperature, high-density plasmas in a small volume.*



Most of the world's fusion energy research effort, the U.S. included, is focused on the magnetic approach (see insert to the left). The FES program, in collaboration with the international fusion community, continues experiments that push the frontiers of the experimental database relevant to burning plasmas. In parallel, computer codes are under development that will accurately predict key aspects of burning plasmas using advances in theory and simulation.

- In 2004, the FES program met its goal of maintaining an average operation time of 90 percent for its three primary collaborative facilities (see Major Collaborative Facilities insert): the DIII-D at General Atomics in San Diego, the Alcator C-Mod at MIT, and the National Spherical Tokamak Experiment at Princeton (SC GG 5.24.1). This supported the key program goal by maintaining the availability of these national facilities to researchers.
- President Bush has decided that the United States should join the negotiations for the construction and operation of a major international magnetic fusion research project. Known as ITER, this project will advance the effort to produce clean, safe, renewable, and commercially available fusion energy.

More detailed information concerning the performance results for the above referenced goals and targets is available in the Performance Results section.

## Challenges and Future Expectations

Basic research supported by SC will provide the first chance for a rigorous test of the most basic predictions of what is thought to be understood about the structure of matter at the smallest scale imagined so far. However, it is not possible to predict what these experiments will provide in terms of technology for the future. Because basic research pushes the frontier of our current understanding of the world we live in, any new discoveries may not immediately or ever lead to practical applications.

We do believe that the most promising scientific fields of the new century are emerging at the boundaries between historically separate disciplines. This is especially true in the fields of chemistry, biology, materials science, and physics. For example, chemists are using atomic force microscopes to reveal the structure of viruses, and physicists are developing sensors that can detect minute quantities of airborne pathogens. Meanwhile, extraordinary breakthroughs in nanoscience – the study of materials at a billionth-of-a-meter resolution – are giving scientists the ability to manipulate individual molecules in their natural environment and develop complex molecular machines the size of microbes and even smaller.

If history is any indicator, then two things are clear: (1) humankind can only profit by having a deeper, more profound understanding of the ultimate structure of the matter making up the universe; and (2) every time something fundamental has been learned about the structure of matter, it has resulted in a benefit to humankind.

DOE has, and will continue to, put together teams of chemists, biologists, physicists, and engineers to pursue research at the intersection of the physical and biological using some of the most advanced imaging and analytical instruments in the nation. We honestly do not know what technologies will result from our basic research investments, but we welcome the opportunity to share the excitement and wonder of our continuing journey of discovery.