Foundations

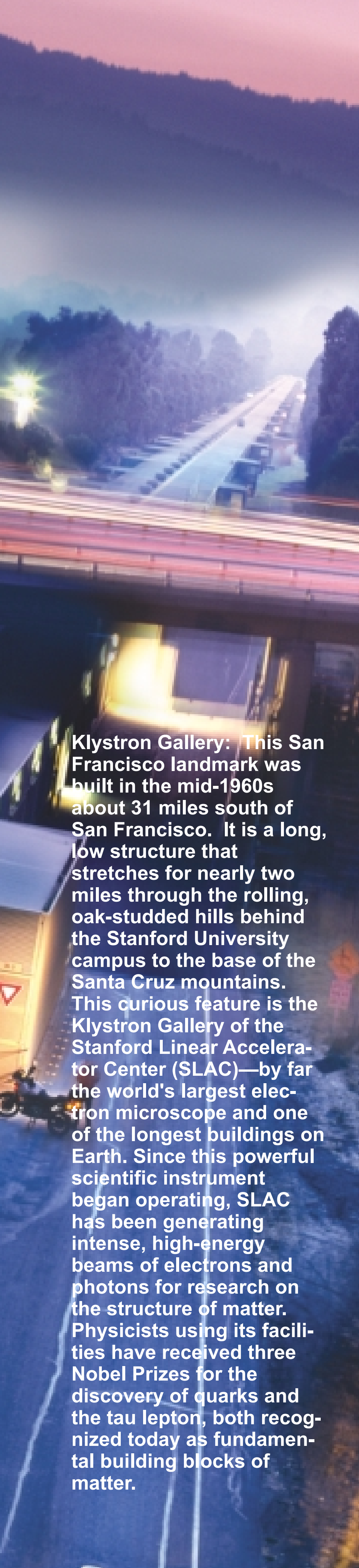
7 Provide the Resource Foundations that Enable Great Science

Create and sustain the discovery-class tools, 21st Century scientific and technical workforce, research partnerships, and management systems that support the foundations for a highly productive, world-class national science enterprise.

Great leaps in the health and well being of our Nation require solid foundations of science. More than half of our national economic growth since 1945 is directly attributable to advances in energy production, energy efficiency, medicine, computation, and other technologies that have their basis in fundamental research. The Office of Science has played a major role in this national success story, contributing scientific advances in nuclear energy, nuclear medicine, advanced computation, genomics, materials science, chemistry, physics, and other areas that have resulted in 35 Nobel Prizes and thousands of industrial patents since DOE's inception in 1977. Modern science, not to mention the scientific endeavor of the future, is different from the science of our past. Increasingly, revolutionary scientific discoveries will involve:

- A complex interplay between scientists from different disciplines
- Scientific tools of incredible power and scope
- The ability to draw from a large pool of scientific and technical talent
- A modern research infrastructure and work environment
- Management practices that deliver outstanding science for each taxpayer dollar.

The Office of Science is uniquely positioned to address many of these challenges, and thus to strengthen the foundations of U.S. science and help lead our Nation into a new era of scientific discovery. No other organization in the world builds and operates such a diverse array of large-scale, discovery-class scientific tools. Furthermore, our track record of envisioning, designing, building, and operating large-scale scientific facilities on time and on budget is unmatched by any other Federal agency, the private sector, or the university community.



Klystron Gallery: This San Francisco landmark was built in the mid-1960s about 31 miles south of San Francisco. It is a long, low structure that stretches for nearly two miles through the rolling, oak-studded hills behind the Stanford University campus to the base of the Santa Cruz mountains. This curious feature is the Klystron Gallery of the Stanford Linear Accelerator Center (SLAC)—by far the world's largest electron microscope and one of the longest buildings on Earth. Since this powerful scientific instrument began operating, SLAC has been generating intense, high-energy beams of electrons and photons for research on the structure of matter. Physicists using its facilities have received three Nobel Prizes for the discovery of quarks and the tau lepton, both recognized today as fundamental building blocks of matter.

SLAC

These facilities and the 10 DOE Office of Science national laboratories that we manage have become national crucibles for interdisciplinary research. In them, our programs can bring the power of thousands of researchers together in multidisciplinary teams to solve large-scale scientific challenges. The Office of Science specializes in scientific challenges that require such facilities and approaches, challenges that are high-risk and high-payoff.

Furthermore, our laboratories are an ideal training ground for young researchers eager to work alongside Nobel laureates and other world-class scientists in multidisciplinary settings. We take pride in managing for excellence in science through rigorous peer and advisory committee reviews of our research, our construction projects, and the way we operate.

Our Strategies

7.1 Provide the discovery-class tools required by the U.S. scientific community to answer the most challenging research questions of our era.

Scientific advancements cannot be made without similar advances in the tools used to make discoveries. Just as the telescope enabled Galileo to see the stars and planets in an entirely new way, new tools being developed by the Office of Science will enable researchers to view our physical world at its extremes—from the tiniest bits of matter to the limits of the cosmos. We call these tools "discovery-class" because they are the best of their kind—they attract the greatest scientific minds in the world and enable the type of discoveries that truly change the face of science.

For more than half a century, the Office of Science has envisioned, designed, constructed, and operated many of the premier scientific research facilities in the world. Today, more than 18,000 researchers and their students from universities, other government agencies, private industry, and abroad use these facilities each year—and this number is growing. For example, the light sources built and operated by the Office of Science now serve more than three times the total number of users they served in 1990. An indication of the ability of these research tools to build bridges between disciplines and open new vistas for research is seen in the dramatic increase—more than 20-fold in the last decade—of life science users at the light sources, once the sole domain of materials and physical science researchers.

Our strategy includes the following emphases:

- Work with the Office of Science programs' advisory committees and the broader scientific community to implement the recommendations of the companion document, *Facilities for the Future of Science: A Twenty-Year Outlook,* and continue to identify and champion those critical facilities that will ensure the U.S. position at the forefront of scientific discovery.

Discovery-Class Scientific Tools

The Office of Science has an unparalleled history of creating discovery-class tools that are available free of charge to the general scientific community and have led to Nobel Prizes and enormous scientific achievement. In the broadest sense, the Office of Science is skilled at creating the following types of scientific tools:

Particle Accelerators and Detectors: These devices are used to study the smallest bits of matter, subatomic particles, and their interactions, and are also used for medical diagnosis and treatment and myriad other applications. Using accelerators, researchers supported by the Office of Science and its predecessors have discovered 10 of the 12 basic constituents of matter (quarks and leptons).

Advanced Light Sources: High-intensity photon and x-ray sources build on core accelerator technology and are used by scientists worldwide to probe materials that cannot otherwise be analyzed. These light sources have led to new medicines, lightweight materials, and a host of other technological innovations.

Neutron Beam Sources: Once the Spallation Neutron Source becomes operational in 2006, the U.S. will regain world leadership in this vital scientific field. Neutron science uses powerful beams of neutrons to probe matter in ways that no other tool can do, opening the door to exciting discoveries in energy production, environmental restoration, and many other areas.

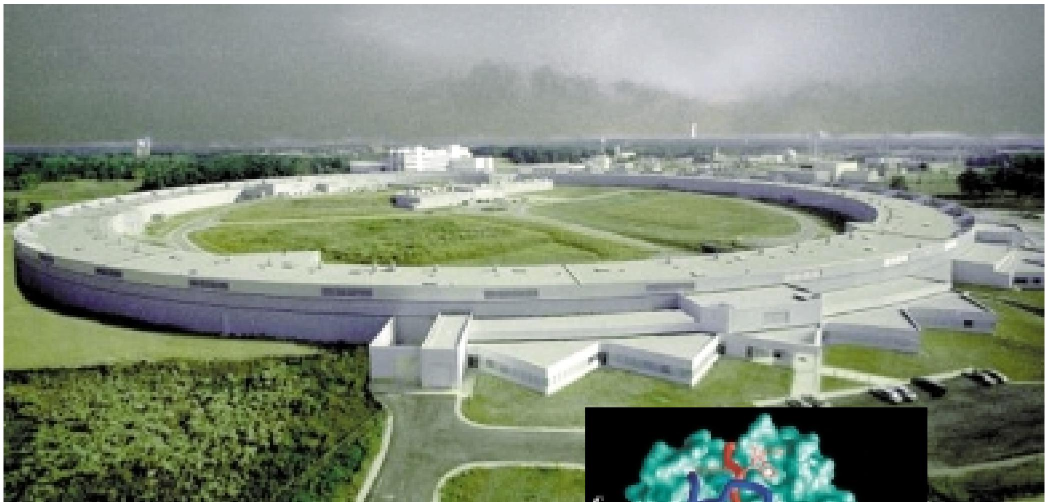
Plasma Science: The Office of Science leads the Nation in the development of tools used to understand plasma phenomena in all its forms. These tools have resulted in a greater understanding of the technology that will be required for a commercial fusion reactor, as well as more immediate uses such as fluorescent lighting and exotic new materials.

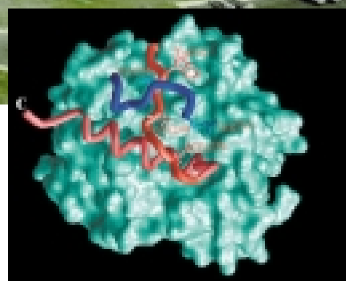
Genome Sequencing Facilities: The Office of Science pioneers many of the underlying technologies and high-throughput capabilities in DNA sequencing, incorporating these developments into its own leading-edge facilities for sequencing living organisms—from primitive microbes and new forms of life to the complex blueprint of human beings.

Specialized Facilities: The Office of Science builds and operates a large number of specialized facilities, including advanced computational centers, computational networking systems, electron-beam microcharacteriza-tion centers, combustion research facilities, centers for materials, and atmospheric radiation monitoring sites.

"It seems to me—and I am not the first to point this out—that we are in the early stage of a revolution in science nearly as profound as the one that occurred early in the last Century with the birth of quantum mechanics. . . . The revolution I am describing is one in which the notion that everything is made of atoms finally becomes operational. For the first time we have tools that give an edge to this sweeping reductionist vision. We can actually see how the machinery of life functions, atom-by-atom. We can actually build atomic-scale structures that interact with biological or inorganic systems and alter their functions. We can design new tiny objects "from scratch" that have unprecedented optical, mechanical, electrical, chemical, or biological properties that address needs of human society. . . . This revolution is caused by two developments: one is the set of instruments such as electron microscopy, synchrotron x-ray sources, lasers, scanning microscopy, and nuclear magnetic resonance devices; the other is the availability of powerful computing and information technology. Together these have brought science finally within reach of a new frontier, the frontier of complexity."

—Presidential Science Advisor John H. Marburger, III, Director of the Office of Science and Technology Policy, Executive Office of the President, at the meeting of the American Association for the Advancement of Science, Boston, Massachusetts, February 15, 2002





ANL

Light sources for major discoveries: The Advanced Photon Source (APS) at Argonne National Laboratory, a research facility funded by the Office of Science, is a major synchrotron radiation light source. Using high-brilliance x-ray beams from the APS, members of the international research community conduct forefront basic and applied research in the fields of materials science; biological science; physics; chemistry; environmental, geophysical, and planetary science; and innovative x-ray instrumentation. The first knotted protein (inset), from a microorganism called *Methanobacterium thermoautotrophicum*, was discovered by researchers using the APS. Protein folding theory previously held that forming a knot was beyond the ability of a protein. This organism is of interest to industry for its ability to break down waste products and produce methane gas.

- Build and operate the next generation of large-scale, discovery-class national research facilities to support the vitality and excellence of U.S. science, which will attract and retain top students and lead to new discoveries.
- Develop partnerships with other Federal agencies, universities, and the U.S. scientific community to fully exploit the extraordinary capabilities and interdisciplinary nature of our user facilities.
- Fully integrate scientific computation and other information technology tools into the fabric of scientific discovery.

Our Timeline for Future Facilities

In the Fall of 2002, the DOE's Office of Science began a major effort to evaluate facility needs and priorities. The process and results are contained in the companion document, the *Twenty-Year Outlook.*

Choosing major facilities is one of the most important activities of the DOE's Office of Science. It requires prioritization across fields of science, a difficult and unusual process. The set of facilities must be phased to conform to scientific opportunities, and to a responsible funding strategy. The largest facilities will often be international in character, requiring both planning and funding from other countries and organizations, together with the U.S.

The 28 proposed facilities are listed by priority in the chart on page 93. Some are noted individually; however, others for which the advice of our advisory committees was insufficient to discriminate among relative priority are presented in "bands." In addition, the facilities are roughly grouped into near-term priorities, mid-term priorities, and far-term priorities (and color-coded red, blue, and green respectively) according to the anticipated research and development timeframe of the scientific opportunities they would address.

Each facility listing is accompanied by a "peak of cost profile," which indicates the onset, years of peak construction expenditure, and completion of the facility. Because many of the facilities are still in early stages of conceptualization, the timing of their construction and completion is subject to the myriad considerations that come into play when moving forward with a new facility. Furthermore, it should be

U.S. Department of Energy Office of Science 20-Year Facility Outlook Peak of Cost Profile

Term	Priority	Program	Facility
Near-Term	1	FES	ITER
Near-Term	2	ASCR	UltraScale Scientific Computing Capability
Near-Term	Tie for 3	HEP	Joint Dark Energy Mission
Near-Term	Tie for 3	BES	Linac Coherent Light Source
Near-Term	Tie for 3	BER	Protein Production and Tags
Near-Term	Tie for 3	NP	Rare Isotope Accelerator
Near-Term	Tie for 7	BER	Characterization and Imaging
Near-Term	Tie for 7	NP	CEBAF Upgrade
Near-Term	Tie for 7	ASCR	Esnet Upgrade
Near-Term	Tie for 7	ASCR	NERSC Upgrade
Near-Term	Tie for 7	BES	Transmission Electron Achromatic Microscope
Near-Term	12	HEP	BTeV
Mid-Term	13	HEP	Linear Collider
Mid-Term	Tie for 14	BER	Analysis and Modeling of Cellular Systems
Mid-Term	Tie for 14	BES	SNS 2-4 MW Upgrade
Mid-Term	Tie for 14	BES	SNS Second Target Station
Mid-Term	Tie for 14	BER	Whole Proteome Analysis
Mid-Term	Tie for 18	NP/HEP	Double Beta Decay Underground Detector
Mid-Term	Tie for 18	FES	Next Step Spherical Torus
Mid-Term	Tie for 18	NP	RHIC II
Far-Term	Tie for 21	BES	National Synchrotron Light Source Upgrade
Far-Term	Tie for 21	HEP	Super Neutrino Beam
Far-Term	Tie for 23	BES	Advanced Light Source Upgrade
Far-Term	Tie for 23	BES	Advanced Photon Source Upgrade
Far-Term	Tie for 23	NP	eRHIC
Far-Term	Tie for 23	FES	Fusion Energy Contingency
Far-Term	Tie for 23	BES	HFIR Second Cold Source and Guide Hall
Far-Term	Tie for 23	FES	Integrated Beam Experiment

Peak Cost ■ Near-term ■ Mid-term ■ Far-term ■

Programs:

ASCR = Advanced Scientific Computing Research
BES = Basic Energy Sciences
BER = Biological and Environmental Research
FES = Fusion Energy Sciences
HEP = High Energy Physics
NP = Nuclear Physics

remembered that construction of these cost profiles was guided by an ideal funding scenario. Appropriate caveats and explanation are provided in the *Twenty-Year Outlook*.

This facility plan represents the DOE Office of Science's best guess today at how the future of science and the need for scientific facilities will unfold over the next two decades. We know, however, that science changes. Discoveries, as yet unimagined, will alter the course of research and the facilities needed in the future. Additionally, we recognize that the breadth and scope of the vision encompassed by these 28 facilities reflects an aggressive and optimistic view of the future of the Office. Nevertheless, we believe that it is necessary to have and discuss such a vision. Despite the uncertainties, it is important for organizations to have a clear understanding of their goals and a path toward reaching those goals. The *Twenty-Year Outlook*, and more broadly, this Office of Science Strategic Plan, offer just such a vision.

7.2 Contribute to a vital and diverse national scientific workforce by providing national laboratory research opportunities to students and teachers.

Our national laboratories offer a unique setting for mentor-intensive training opportunities, helping to ensure that DOE and the Nation have a highly skilled and diverse scientific and technical workforce. These capabilities strongly complement the career development opportunities provided by the National Science Foundation and other Federal agencies. Our national laboratories provide an environment where, under the mentorship of world-class scientists, students and teachers have unparalleled opportunities to perform exciting research with the most advanced instrumentation available. This combination

Science and Technology Workforce Development—A National Crisis

Our Nation is failing to produce both a scientifically literate citizenry and the kind of workforce we will need in the 21st Century. Consider the following:

- Test scores placed U.S. students near the bottom of the 16 nations that administered physics and advanced math tests.
- U.S. engineering majors declined by 35% between 1975 and 1998.
- Only 19,000 degrees in the physical sciences were granted in the U.S. in 1999, compared with 130,000 social science degrees.

The disturbing statistics go on and on, but this decline can no longer be tolerated by a Nation that aspires to lead the world in science and technology. As the U.S. Commission on National Security in the 21st Century reported, "Inadequacies of our systems of research and education pose a greater threat to U.S. national security over the next quarter century than any potential conventional war that we might imagine."

of mentor talent and advanced instrumentation greatly serves to attract, develop, and retain a diverse and capable workforce. Our strategy includes the following emphases:

- Provide undergraduate internships for students entering science, technology, engineering, and math (STEM) careers, including K-12 science and math teaching careers.
- Provide graduate/faculty fellowships for STEM teachers and faculty.
- Develop partnerships with other Federal agencies to address the long-term decline in undergraduate and graduate degrees in the physical sciences.

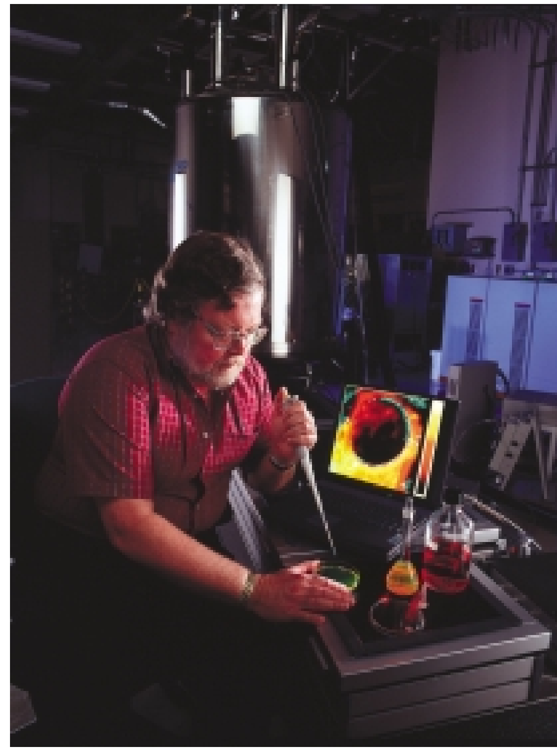
7.3 Strengthen national laboratory, university, and industry partnerships to work on the science challenges facing our Nation.

The Office of Science manages 10 DOE national laboratories, home to many of the premier scientists and facilities the United States has to offer, and makes direct investments in over 280 universities located across the Nation through research grants and other activities. We also work with high-technology companies, such as General Motors and Cray, to explore advanced technologies and solutions that quickly find their way into the marketplace. As one of the few organizations in the world that manages such a diverse portfolio of research performers, the Office of Science has a unique opportunity to bring the power of these research teams to work at the extreme frontiers of science.

Researchers at the national laboratories will benefit from these partnerships through increased access to scientific talent and capabilities that are only found in universities, while universities will benefit through greater training opportunities for students, access to scientific tools unavailable at universities, and participation in multidisciplinary teams of researchers. Industry, increasingly, is seeing the benefit of tapping into the Federal government's deep reservoir of scientific resources to maintain U.S. economic competitiveness.

In addition, the Office of Science works closely with other Federal agencies and major DOE applied research programs to fully leverage the Federal investment in science. We work with the National Institutes of Health to develop new medical technologies; with NASA to explore the cosmos; with the National Science Foundation on fundamental physics, advanced computation, and nanoscience; and with other DOE programs to develop new energy options and solutions. Overall, key scientific disciplines will be strengthened through this interchange of people and ideas.

We recognize that the very nature of science and the exchange of ideas within the scientific community benefits greatly from open communications and collaborations. In the future, it will be necessary to preserve and protect the openness and



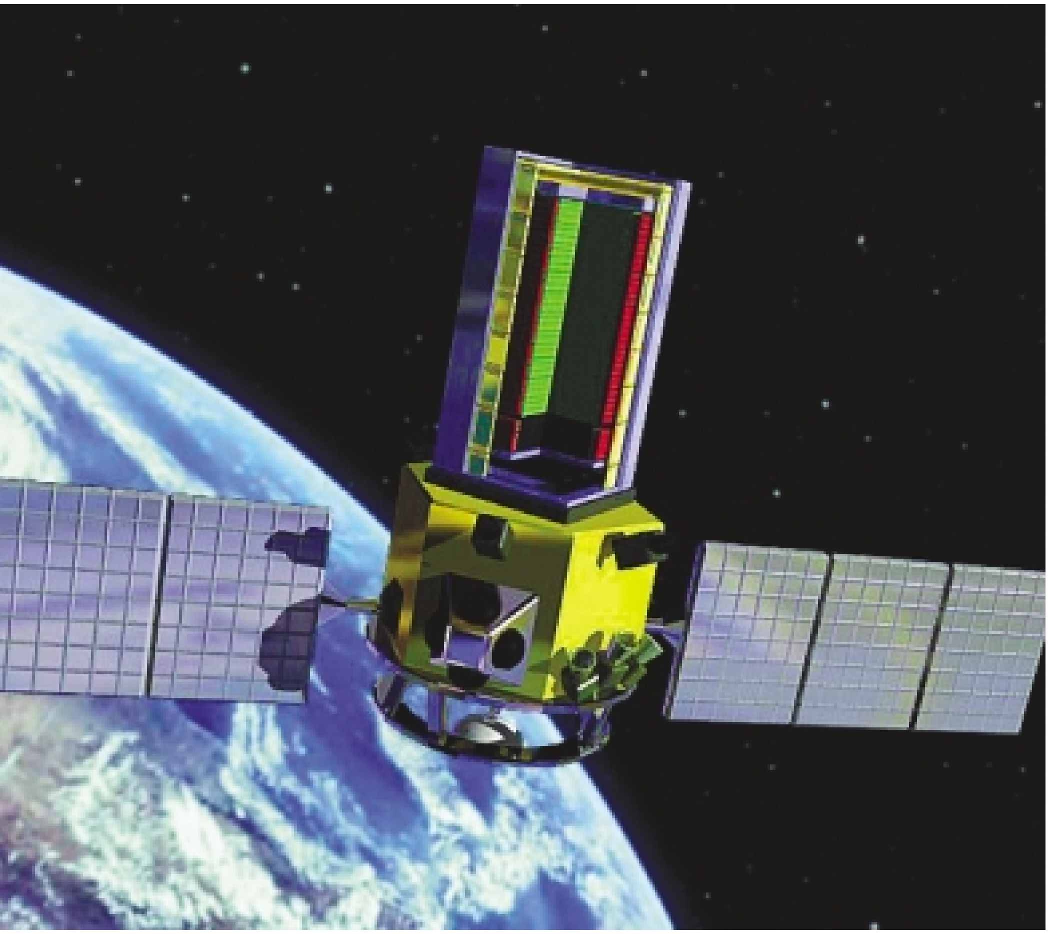
PNNL

Partnership for a new science imaging technology: Scientists from the Pacific Northwest National Laboratory and the Massachusetts Institute of Technology developed a system that images "live" cellular systems using both optical microscopy and nuclear magnetic resonance (NMR) microscopy. The NMR image works like a magnetic resonance imaging unit at a modern hospital, except that it examines down to a single cell and its nucleus. This noninvasive technique will enable scientists to monitor how live cells respond as they are exposed to environmental changes, such as heat, chemicals, and radiation. Scientists will also be able to see what happens when cells are exposed to multiple contaminants at the same time, and ultimately, to relate these responses to large-scale efforts.

strength of our scientific institutions, while at the same time exercising greater control of the free dissemination of scientific information that has important national security implications. This delicate balance will be developed carefully and in consultation with the science community to ensure that a "do no harm" philosophy is followed.

Our strategy includes the following emphases:

- Encourage the creation of partnerships among national laboratory, university, and industrial researchers to tackle major multidisciplinary scientific challenges, such as development of new materials through nanoscience and high-end computational simulation.
- Expand access and operating time at key scientific user facilities to enable national partnerships that address significant national challenges.
- Strengthen relationships with minority institutions to increase the diversity of science and performers available within the U.S. scientific enterprise.
- Establish high-speed information connections among teams of researchers located at diverse locations, while improving remote access to scientific user facilities.
- Strengthen ties between our science programs and DOE-led national initiatives in nuclear energy, hydrogen fuel, bio-based fuels, climate change, carbon management, and nonproliferation through sustained, coordinated programs.
- Foster cooperation among Federal science agencies to enhance the impact and benefit of our jointly held assets, particularly in emerging areas of national need, such as advanced computation, nanoscience, climate change, and genomics.
- Build international partnerships where national resources can achieve global benefits and gain leverage from participation of collaborating nations.



The Gamma-Ray Large Area Space Telescope (GLAST): NASA and DOE's Office of Science are teaming to bring the astrophysics and particle physics communities together to map the high-energy gamma ray sky. These gamma rays come from sources like active galactic nuclei, supernovae remnants, black holes, and neutron stars. GLAST can also search for dark matter candidate particles and other high mass relics from the early universe. Launch is expected in 2006.

- Participate in the development of national policies for the sharing of scientific and technical information, achieving a careful balance between the need for scientific openness and security interests.

7.4 Manage the Office of Science's research enterprise to the highest standards, delivering outstanding science and new discoveries that improve our Nation's health and economy.

Extraordinary discoveries depend strongly on the extraordinary management of the Nation's science enterprise. Our management agenda is designed to ensure that the national scientific enterprise benefits as broadly and fully as possible from the decisions we make and the work we do. This means carefully managing not only the science we produce, but also the institutions and other resources that support our science programs.

The Office of Science has a large workforce, a national scientific enterprise that spans state and national borders, and five decades of experience managing national scientific programs. We manage an annual budget comparable to the gross domestic product of many countries. Our national laboratory complex has no peer in the world in the size and diversity of its research. We sponsor research at universities and other institutions throughout the country. Our research programs have been very successful, yielding major advances in human knowledge, with substantial benefits to the Nation's economy.

The outstanding success of our research hinges on two key principles:

1) *Long-term strategic investments in people, partnerships, and high-risk research:* The Office of Science takes big scientific risks and expects

Integrated Management in the Office of Science

The Office of Science's integrated management philosophy can be summed up as follows:

"Anticipate and manage the full range of issues that affect our ability to deliver excellent science and scientific services to the Nation."

Operationally, this means that we ensure that all of the non-research activities at the 10 DOE Office of Science national laboratories are managed to the highest standards of efficiency, safety, and productivity. In this way, we know that all available resources are focused on our primary goal—delivering great science that supports DOE's missions and enables our Nation to meet major national challenges.

We are adopting a comprehensive approach to integrated management that builds on the success of a major initiative in the late 1990s that integrated safety management practices into all facets of work planning and execution at our national laboratories. This included business practices, infrastructure, maintenance, safeguards and security, safety, and stakeholder relations.

We will expand upon our past successes by integrating all other aspects of operations into our scientific programs at the laboratories. A good example of how this is already being done is through contract performance measures. Our laboratory contractors are evaluated annually for their management of science and operational programs. Their performance in these areas, taken together, determines the overall performance rating they receive from the Office of Science.

We are now exploring which management systems, if any, need to change; where integration should take place; and what level of integration is required. Major initiatives underway that will lead to a full implementation of integrated management within the Office of Science include restructuring, strategic planning, a Model Contract Initiative, contractor self-assessment programs, and development of better performance metrics.

SLAC

State-of-the-art instrumentation critical for great science: Technicians manufacture complex copper structures for use as accelerator components that operate under high electric fields and high vacuum conditions. These components must be fabricated in state-of-the-art facilities, requiring the modern infrastructure and corresponding work environment that leads to high precision equipment, and ultimately, to great science. These copper structures are intended for use in the two-mile-long linear accelerator (linac) at the Stanford Linear Accelerator Center, a premier user facility available to scientists worldwide. The linac contains over 80,000 copper discs and cylinders that must be brazed together.

and achieves high payoffs. We make long-term investments in people and research programs, while responding with agility to rapid changes at the frontiers of science. We balance our support for big science and interdisciplinary teams with a broad portfolio of projects conducted by leading university and laboratory investigators and collaborative groups. Underpinning these efforts is an uncompromising commitment to scientific excellence and integrity. We are in the business of discovery and, therefore, we value bright minds and new ideas as much as efficiency and productivity.

2) *Systematic assessment of major projects, programs, and institutions:* Every research activity that we support with U.S. taxpayer dollars is assessed to ensure that the quality, relevance, and performance of DOE Office of Science programs meet the highest standards. Each major construction project, all of our scientific user facilities and national laboratories, and significant elements of each Office of Science research portfolio are reviewed regularly according to established procedures, frequently with the help of external experts to ensure that we achieve our goals.

Consistent with these two principles, we have adopted two distinct kinds of management practices. First, we invest in people and institutions, so we follow established business practices such as integrated safety management that would be recognized by any U.S. corporate executive as current and effective.

Second, we sponsor basic research, which requires an entirely different set of management practices designed to ensure that the best scientific opportunities are pursued. These practices include the extensive use of peer and merit review to monitor the quality and relevance of the science we sponsor; a reliance on the advice and guidance of the U.S. scientific community through six independent advisory committees; and the employment of highly skilled program managers who nurture critical scientific disciplines and provide the multi-year continuity of support that is often needed to meet difficult technical challenges. These practices help ensure that the U.S. taxpayer receives the highest possible return on the science investment that our Nation makes.

The intersection between traditional management practices and those that are unique to the scientific community is clearest in the way that we construct and operate the large discovery-class scientific user facilities that are a signature feature of the Office of Science. Constructing scientific facilities pushes the envelope of science and technology to the frontiers, and they are considered huge engineering projects by any standard.

Improve our overall performance.

The Office of Science is committed to performance. We have embarked on a comprehensive restructuring of our organization that is designed to increase performance-based management practices, reduce management layering, enhance integration, guarantee line accountability, simplify internal processes, and increase worker productivity. All of these management strategies, however, are being carefully implemented to reflect the unique nature of basic research and the long-term nature of our investments. Our strategy includes the following emphases:

- Consolidate and streamline financial, budgetary, procurement, personnel, program, and performance information to communicate faster and at less cost.
- Use new information management technologies to streamline project funding, facilitate a portfolio view of R&D, and enhance communication across Federal offices and organizations.
- Re-engineer laboratory management contracts to improve contractor performance, enhance line management accountability, and give the Office of Science and its contractors the flexibility needed to manage for results.
- Develop an integrated approach to planning, program execution, and performance management that sets the benchmark for a Federal basic research organization.
- Employ a highly competent Federal workforce capable of continuing the Office of Science's tradition of discovery into the future.

Establish a modern laboratory system, fully capable of delivering the science our Nation requires.

The DOE Office of Science laboratory system includes hundreds of research labs, offices, and specialized scientific facilities distributed over eight states and accessed by more than 25,000 scientists worldwide. The loss to the science community would be immense if we stopped upgrading, operating, and providing access to this incredible research complex. However, 24% of the buildings in the Office of Science laboratory system have reached or are reaching the end of their serviceable lives.

In addition to making targeted investments that maximize our rehabilitation efforts, our strategy includes examining our total portfolio of facilities and seeking to expand their utility. Our strategy includes the following emphases:

- Size our facilities to scientific demand, including investing in new replacement support facilities where needed and removing excess facilities.
- Increase our annual laboratory maintenance investment to a level consistent with nationally recognized standards (i.e., generally 2 to 4% for conventional facilities).
- Increase the overall functionality of general-purpose facilities by significantly increasing our annual capital investment.
- Support greater flexibility in the use of funds for maintenance and modernization.