Four Years Later: An Interim Report on *Facilities for the Future of Science: A Twenty-Year Outlook*

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Facilities for the Future of Science: A Twenty-Year Outlook was published in November 2003. The original publication is available online, on the DOE Office of Science web site, under Scientific User Facilities at http://www.science.doe.gov/.

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Contents

Introduction

The Department of Energy (DOE) Office of Science 2003 publication *Facilities for the Future of Science: A Twenty-Year Outlook* was the first long-range facilities plan prioritized across disciplinary lines ever issued by a government science funding agency anywhere in the world. The Office of Science publication listed 28 proposed facilities, ranking them along two dimensions: scientific priority and technological readiness.

The document has served as a roadmap, providing an overarching strategic framework and long-term vision to guide year-by-year DOE policy and funding decisions. Significant progress has been made in implementing the plan and deploying many of the planned facilities.

At the same time, contemporary science and technology are undergoing change, as always, and the Office has been careful not to adhere with inappropriate rigidity to the 2003 snapshot, but to respond to technological progress in reordering and restructuring its priorities.

This *Interim Report* provides a summary update on the status of the facilities listed in the *Twenty-Year Outlook*. In many cases, substantial progress has been made toward deployment. Some planned facilities have been accelerated; a number have been reoriented, some in a substantial way. One was terminated in light of facilities abroad.

In addition to updating the reader on the current status of the facilities and recalling the special contributions these facilities can make to science and American economic competitiveness, the document provides background on the facilities and our decision-making. In cases where Department decisions about facilities have changed, a summary of the rationale behind the Department's decisions is provided.

Our purpose is to give our citizens, legislators, and stakeholder communities a relatively digestible summary of where our Facilities Outlook stands today—and a flavor for the continual careful effort of analysis, evaluation, and internal and external review that goes into our facilities planning and decision-making.

Interested readers can find a wealth of additional information on particular facilities on our website (www.science.doe.gov) and the websites of the DOE National Laboratories.

The DOE Office of Science is the primary federal supporter of basic research in the physical sciences. The world-leading scientific facilities we create, maintain, and operate are the key to continued U.S. leadership in physical and biological science research. This leadership, and the transformational scientific discoveries that flow from it, are critical to meeting the challenges our Nation faces in the twenty-first century in the areas of both global economic competitiveness and energy security.

These facilities are among the world's most powerful tools for scientific discovery. I hope the reader will share our excitement over the opportunities they provide our Nation and our world.

Raymond L. Orbach

Dr. Raymond L. Orbach
Under Secretary for Science
U.S. Department of Energy

The Twenty-Year Facilities Outlook—A Prioritized List

The U.S. Department of Energy Office of Science leads the world in the conception, design, construction, and operation of large-scale research facilities.

In November 2003, in *Facilities for the Future of Science: A Twenty-Year Outlook,* DOE proposed a portfolio of 28 prioritized new scientific facilities and upgrades of current facilities spanning the scientific disciplines to ensure the U.S. retains its primacy in critical areas of science and technology well into the next century.

The 28 facilities are listed by priority on the following pages of this *Interim Report*, in the same format used in the original publication.

Some are noted individually; however others, for which the advice of Office of Science program 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) over the full twenty-year period, according to the anticipated R&D timeframe of the scientific opportunities they would address.

The chart on the next page lists the 28 facilities as of the original publication in November 2003, including their R&D, conceptual design, engineering design, construction, and operation status at that time.

The charts on pages 8 and 9 show the updated list of facilities and their projected status, respectively, by the conclusion of the 2007 fiscal year, ending September 30, 2007, and by the conclusion of the 2008 fiscal year, ending September 30, 2008.

Construction of these new facilities and upgrades of current facilities, integrated with the plans of other U.S. science agencies over the next twenty years, will sustain—in the best American tradition—the flow of seminal scientific ideas and extraordinary technological innovation that are so critical to growing the U.S. economy and enhancing our way of life.

Status of Facilities in 20-Year Outlook

As of November 2003

Term	Priority	Program	Facility	R&D	Conceptual Design	Engineering Design	Construction	Operation
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 Aberration Corrected Microscope					
Near-Term	12	HEP	BTeV					
Mid-Term	13	HEP	Linear Collider					
Mid-Term	Tie for 14	BER	Analysis/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					

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Programs:

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

Status of Facilities in 20-Year Outlook

By the end of FY 2007

Term	Priority	Program	Facility		R&D	Conceptual Design	Engineering Design	Construction	Operation
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 →	Bioenergy Research Centers*					
Near-Term	Tie for 3	NP	Rare Isotope Beam Facility (previously RIA) #						
Near-Term	Tie for 7	BER	Characterization and Imaging →	Bioenergy Research Centers*					
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 Aberration Corrected Microscope						
Near-Term	12	HEP	BTeV #		Terminated				
Mid-Term	13	HEP	International Linear Collider						
Mid-Term	Tie for 14	BER	Analysis/Modeling of Cellular Systems →	Bioenergy Research Centers*					
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 →	Bioenergy Research Centers*					
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, eLIC, or the Electron Ion Collider						
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-High Energy Density Physics Experiment						

75-100% 50-75% 25-50% > 0% complete

** technological readiness change*
 # changed due to planned facility abroad

Status of Facilities in 20-Year Outlook

By the end of FY 2008

Term	Priority	Program	Facility		R&D	Conceptual Design	Engineering Design	Construction	Operation
Near-Term	1	FES	ITER		75-100%	75-100%	75-100%	> 0%	
Near-Term	2	ASCR	UltraScale Scientific Computing Capability		75-100%	75-100%	50-75%	25-50%	25-50%
Near-Term	Tie for 3	HEP	Joint Dark Energy Mission		50-75%				
Near-Term	Tie for 3	BES	Linac Coherent Light Source		75-100%	75-100%	75-100%	50-75%	
Near-Term	Tie for 3	BER	Protein Production and Tags →	Bioenergy Research Centers*	75-100%	75-100%	50-75%	> 0%	> 0%
Near-Term	Tie for 3	NP	Rare Isotope Beam Facility (previously RIA) #		25-50%				
Near-Term	Tie for 7	BER	Characterization and Imaging →	Bioenergy Research Centers*	75-100%	75-100%	50-75%	> 0%	> 0%
Near-Term	Tie for 7	NP	CEBAF Upgrade		75-100%	75-100%	75-100%		
Near-Term	Tie for 7	ASCR	ESnet Upgrade		75-100%	75-100%	75-100%	50-75%	50-75%
Near-Term	Tie for 7	ASCR	NERSC Upgrade		75-100%	75-100%	75-100%	50-75%	50-75%
Near-Term	Tie for 7	BES	Transmission Electron Aberration Corrected Microscope		75-100%	75-100%	75-100%	25-50%	> 0%
Mid-Term	12	HEP	BTeV #		Terminated				
Mid-Term	13	HEP	International Linear Collider		> 0%				
Mid-Term	Tie for 14	BER	Analysis/Modeling of Cellular Systems →	Bioenergy Research Centers*	75-100%	75-100%	50-75%	> 0%	> 0%
Mid-Term	Tie for 14	BES	SNS 2-4 MW Upgrade		25-50%	25-50%	> 0%		
Mid-Term	Tie for 14	BES	SNS Second Target Station		25-50%				
Mid-Term	Tie for 14	BER	Whole Proteome Analysis →	Bioenergy Research Centers*	75-100%	75-100%	50-75%	> 0%	> 0%
Mid-Term	Tie for 18	NP/HEP	Double Beta Decay Underground Detector		50-75%				
Mid-Term	Tie for 18	FES	Next-Step Spherical Torus		25-50%				
Mid-Term	Tie for 18	NP	RHIC II		50-75%				
Far-Term	Tie for 21	BES	National Synchrotron Light Source Upgrade*		75-100%	75-100%	50-75%	> 0%	
Far-Term	Tie for 21	HEP	Super Neutrino Beam		> 0%				
Far-Term	Tie for 23	BES	Advanced Light Source Upgrade		> 0%				
Far-Term	Tie for 23	BES	Advanced Photon Source Upgrade		> 0%				
Far-Term	Tie for 23	NP	eRHIC or eLIC or Electron Ion Collider		> 0%				
Far-Term	Tie for 23	FES	Fusion Energy Contingency						
Far-Term	Tie for 23	BES	HFIR Second Cold Source and Guide Hall		> 0%				
Far-Term	Tie for 23	FES	Integrated Beam-High Energy Density Physics Experiment		> 0%				

Legend: 75-100% | 50-75% | 25-50% | > 0% complete

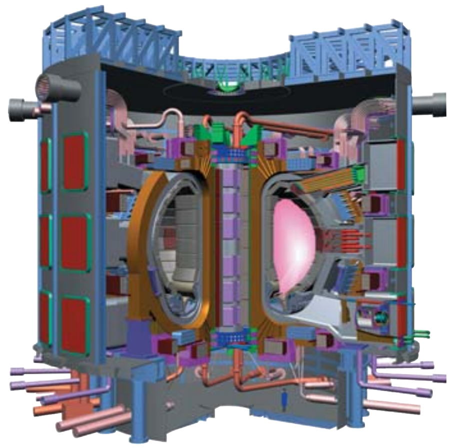
** technological readiness change*
 # changed due to planned facility abroad

Facility Summaries

Near-Term Priorities

Priority: 1
ITER

As U.S. and global energy demand rapidly expands over the next century, the search for new abundant and environmentally friendly sources of energy becomes ever more urgent. One of the most powerful potential global energy solutions—if it proves feasible—will be fusion.



The ITER device is based on the tokamak concept, in which a hot gas is confined in a torus-shaped vessel using a magnetic field. The gas is heated to over 100 million degrees and will produce 500 MW of fusion power.

Fusion is the energy that powers the sun and the stars. Fusion creates energy from elements abundantly available on earth and produces no greenhouse gases or spent nuclear fuel in the process. The scientific challenge here is to create fusion energy in a sustained form and contain it—with its 100 million degrees-plus Celsius temperatures—on earth. Over the years, scientists have made substantial progress in containing fusion reactions using powerful magnetic fields. Now the United States has teamed with the European Union, Japan, the Russian Federation, China, South Korea, and India to construct ITER, a large-scale experimental fusion reactor designed to demonstrate a sustained fusion reaction in a power plant-like environment.

If successful, ITER will be a major step forward in the effort to produce clean, safe, renewable, and commercially-available fusion-generated energy by the middle of this century. Commercialization of fusion energy would dramatically reduce America's dependence on imported oil, cut global greenhouse gas emissions, and provide a virtually inexhaustible source of energy. ITER will be the largest and most technologically sophisticated fusion experiment, and it is the first truly international large-scale scientific experiment in the world.

Update: The United States signed the ITER agreement with six international partners in November 2006. Construction of ITER is scheduled to begin in FY 2008 in Cadarache, France, with the U.S. providing $1.12 billion in funding and in-kind contributions (9.1 percent share) during the construction phase. The preliminary schedule calls for completing the U.S. contribution to ITER construction in FY 2014, with "first plasma" expected in FY 2016.

- On January 30, 2003, President Bush announced that the United States would join negotiations with the European Union, Japan, and Russia to create the International Thermonuclear Experimental Reactor, or ITER.

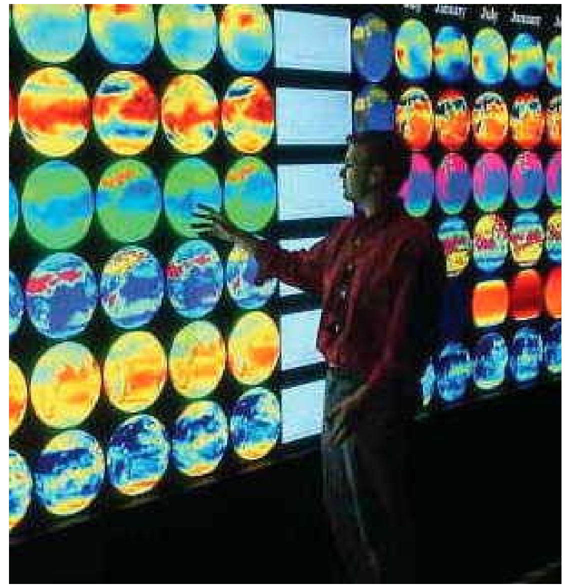
- On November 21, 2006, representatives of the seven ITER Parties (now including China, the Republic of Korea and India) signed the ITER agreement, the first-of-its-kind international collaboration to build a major scientific facility of this scale. The agreement established an ITER organization. It designated Cadarache, France, adjacent to the main research center of the French Atomic Energy Commission, as the host site for construction. And it established funding shares by the participating Parties. The agreement is expected to be ratified by all parties by the end of 2007.

- The European Union, as the host, will provide 45.5 percent of the construction phase funding. The U.S., as a non-host partner, will participate in the construction phase at the level of 9.1 percent. The total value of the U.S. contribution is $1.12 billion, about 80 percent of it in in-kind goods and technology.

- Construction of ITER at the Cadarache site will begin in FY 2008. The FY 2008 Budget Request for the DOE Office of Science provides $160 million for ITER activities, including the beginning of U.S. long-lead procurement of in-kind items. U.S. ITER activities are managed by the U.S. ITER Project Office at Oak Ridge National Laboratory (ORNL). Working with ORNL currently are two partner institutions, Princeton Plasma Physics Laboratory and Savannah River National Laboratory.

Priority: 2
UltraScale Scientific Computing Capability

The supercomputer is one of science's newest and most formidable tools, enabling researchers to model and simulate experiments that could never be performed in a laboratory. Some see computer modeling and simulation as a new "third pillar" of scientific discovery, side by side with experiment and theory. Supercomputing also has implications for U.S. economic competitiveness, for it holds out the promise of enabling U.S. industry to perform "virtual prototyping" of complex systems and products, substantially reducing development costs and shortening time to market. The Office of Science has been leading the way in developing the nation's civilian supercomputing capabilities, acquiring ever-faster machines, nurturing the complex software development knowledge necessary to take advantage of these unprecedented processing capabilities, and helping to bootstrap the U.S. supercomputer industry. Scientists are using the Office of Science's high-speed computational resources to understand combustion processes, model fusion reactions, analyze climate change data, reveal chemical mechanisms of catalysts, and study the collapse of a supernova, among scores of other applications.



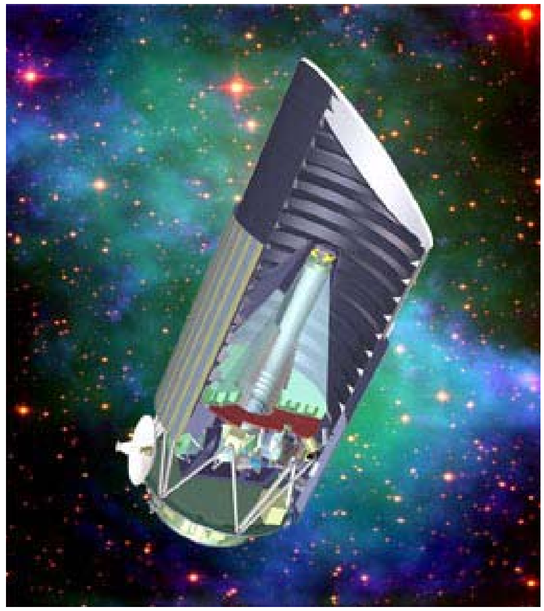
Visualization capabilities illuminate high-performance computing data from large-scale climate simulations.

Update: In 2004, the Office of Science began to add dramatically to the supercomputing capabilities in the DOE National Laboratory complex, partnering with industry in the development of new hardware and architectures. Leadership Computing Facilities have been established at Oak Ridge National Laboratory (with an 18.5 teraflop Cray X1E and 119 teraflop Cray XT3) and at Argonne National Laboratory (with a 5.7 teraflop IBM Blue Gene/L). Japan formerly dominated the field of civilian supercomputing with its Earth Simulator. DOE now leads the world in civilian computing. Capabilities are expected to reach a petaflop (1,000 teraflops) by the end of 2008. (A teraflop is a trillion floating point operations—or mathematical calculations—per second.)

- In 2004, following a peer-reviewed proposal process, the partnership of Oak Ridge National Laboratory (ORNL), Argonne National Laboratory (ANL), and Pacific Northwest National Laboratory (PNNL) was selected to provide Leadership Computing Capability for Science.
- The first Leadership Computing Facility (LCF) was established using Cray computers at ORNL in 2004. Currently the LCF at ORNL has an 18.5 teraflop Cray X1E and a 119 teraflop Cray XT3.
- The second LCF was established at ANL in 2006 and has a 5.7 teraflop IBM Blue Gene/L.
- Current plans call for the ANL LCF to acquire a 100 teraflop IBM Blue Gene/P in 2007 and a follow-on upgrade to between 250 and 500 teraflops in 2008.
- The LCF at ORNL plans to upgrade the Cray XT3 to 250 teraflops in 2007 and plans to acquire a petaflop Cray Baker system in 2008.
- Annually, 80 percent of the Leadership Computing Facility resources are allocated through the *Innovative and Novel Computational Impact on Theory and Experiment* (INCITE) program, which is a competitively selected, peer and readiness reviewed process open to researchers from academia, industry, government and non-profit organizations.

Priority: Tie for 3
Joint Dark Energy Mission (JDEM)

In 1998, two independent research teams stunned the scientific world with the discovery that the universe is expanding at an accelerating rate. Their discovery implied the existence of a mysterious "Dark Energy" that is working against gravity to push the universe apart. Dark Energy actually accounts for about 70 percent of the energy budget of our universe. Following the discovery of the existence of Dark Energy, DOE and the National Aeronautics and Space Administration (NASA) developed a concept for a Joint Dark Energy Mission. The purpose would be to put a satellite probe in space to achieve a more precise measurement of the rate of the universe's acceleration and thereby provide new data to help solve the Dark Energy mystery. The probing of Dark Energy promises to deepen our understanding of the fundamental physical laws and the origins of our universe.

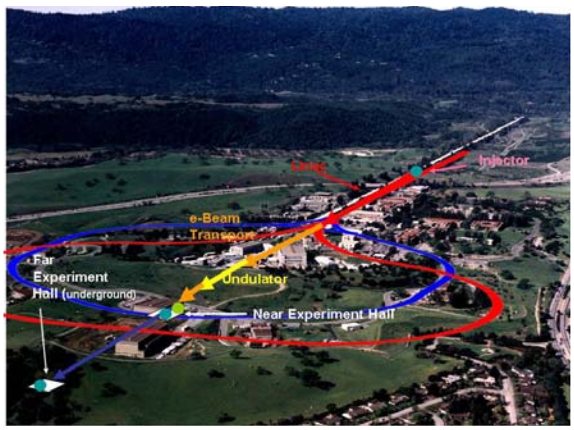

The Joint Dark Energy Mission's space-based probe will study the accelerating universe.

Update: Several competing projects for probing the universe's dark energy have emerged since the formation of JDEM between DOE and NASA and the development of the specific JDEM proposal for a space-based SuperNova/Acceleration Probe (SNAP) to measure the rate of the universe's acceleration. In August 2006, DOE and NASA agreed to jointly commission a National Academy of Sciences study to advise NASA by identifying the highest priority among the five competing projects in NASA's "Beyond Einstein" program (three of which, including SNAP, focus on dark energy).

- The High Energy Physics Advisory Panel established a Dark Energy Task Force to provide advice to NASA, DOE, and the National Science Foundation. Its report, released in June 2006, recommended multiple methods for studying dark energy at each stage.
- DOE continues to support R&D for both near-term and next-generation ground- and space-based dark energy concepts.

Priority: Tie for 3
Linac Coherent Light Source (LCLS)

One of the major drivers of scientific progress today is our ability to image matter on ever smaller scales of space and time. This improved understanding of the behavior of matter at the nanoscale and in ultrafast time intervals provides scientists with an ability to manipulate matter to unprecedented degrees. The resulting breakthroughs will lead to revolutionary new materials with unprecedented combinations of properties—strength and weight, flexibility and resilience, etc.—for a host of applications throughout the American economy, promoting progress in energy, transportation, construction, electronics, and medicine, to name only a few fields. Some of the most important tools in the Office of Science complex—and some of the most promising we are in the process of deploying—are the advanced, high-intensity light sources used for probing matter at the sub-microscopic level.



The Linac Coherent Light Source will be the world's first x-ray-free electron laser, opening new realms of scientific research in chemical, materials, and biological sciences.

Of these light sources, the Linac Coherent Light Source deserves special mention. The LCLS, under construction at the Stanford Linear Accelerator Center, will be the world's first free electron laser. It will have the ability to deliver x-rays at such short wave-lengths and on such a brief time scale as to enable scientists for the first time to observe chemical reactions at the molecular level in real time.

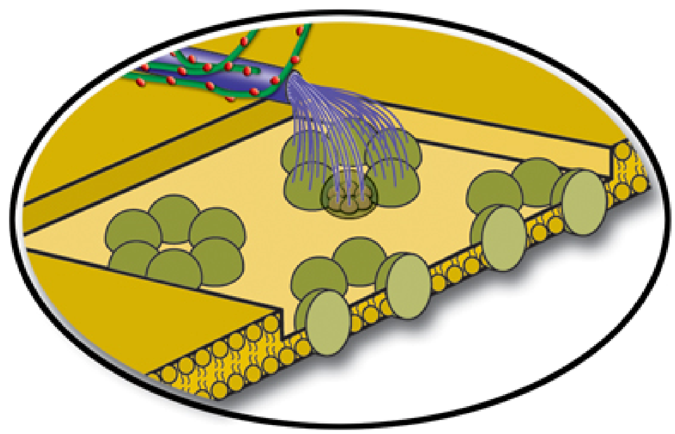
A century ago, x-rays astonished humanity by giving human beings a glimpse inside their own bodies. LCLS can lead to comparable revelations about the world at the nanoscale and below, with countless potential applications to medicine, pharmaceuticals, electronics, materials science, nanotechnology, and fields not yet invented.

Update: The LCLS is in construction at the Stanford Linear Accelerator Center, as planned in 2003. Project Engineering and Design funding for the LCLS began in FY 2003, and construction funding began in FY 2005. The next major milestone—to approve start of initial operations—is planned for FY 2009.

- The LCLS will be the world's first x-ray free electron laser when it becomes operational.
- The LCLS will have x-ray emission properties that vastly exceed current synchrotron x-ray sources in three areas—peak brightness (intensity); spatial coherence (laser-like beam quality); and ultrashort pulses (230 femtoseconds or less). The short pulse and high degree of spatial coherence in the LCLS beam will make its peak brightness in the x-ray range roughly ten orders of magnitude greater than that of current synchrotron light sources.
- These characteristics will enable frontier science in areas that include discovering and probing new states of matter, understanding and following chemical reactions and biological processes in real time, imaging chemical and structural properties of materials on the nanoscale, and imaging non-crystalline biological materials at atomic resolution one molecule at a time. The LCLS project is a collaboration of three National Laboratories and universities.

Priority: Tie for 3
Genomics:GTL Bioenergy Research Centers

Among the major options for reducing our nation's dependence on fossil fuels and imported oil, biofuels rank among the most promising. Biofuels produced from biomass, such as cellulosic ethanol, could replace perhaps as much as a third of the current U.S. demand for transportation fuels with a homegrown, renewable energy source without affecting food production. In addition, biofuels offer a major answer to both pollution and greenhouse gases: they burn more cleanly and are essentially carbon-neutral (plants that are grown as biofuel feedstocks reabsorb the carbon dioxide that is emitted when the biofuels are burned).



Molecular machines in plant cell walls synthesizing strands of cellulose, the most abundant polymer on Earth. Research breakthroughs to efficiently deconstruct cellulose and other plant biomass into sugars will be key to their fermentation into biofuels.

Developing truly cost-effective methods for producing biofuels on an industrial scale will require breakthroughs in basic science. The development of commercially viable processes for the conversion of cellulose or plant fiber into fuel, in particular, poses technological challenges that have not yet been solved.

Fortunately, over the past decades, we have made enormous strides in biotechnology. Many scientists believe biotechnology may hold the key to making biofuels cost-effective. DOE, as the originator of and later as a major partner in the Human Genome Project, has pioneered many of the major advances and developed many of the new tools of the biotech revolution: high-throughput genome sequencing, high-intensity light sources for the imaging of life at molecular scales, and a variety of other state-of-the-art instruments for understanding biology at the system, cellular, and molecular levels. The Office of Science's Genomics:GTL program, as the heir to the Human Genome Project, has continued to pursue these discoveries, probing the microbial world for innovative biotech solutions to the Department's missions in energy, carbon capture, and environmental clean-up.

Today the Genomics:GTL program is preparing to deploy three new Bioenergy Research Centers. Each will support a multidisciplinary scientific team working together in the urgent pursuit of cutting-edge biotech research on microbes and plants aimed at achieving the necessary breakthroughs for cost-effective biofuel conversion and production. The centers will explore a range of options for biofuel and bioenergy, including cellulosic ethanol and other forms of biofuel.

UPDATE: DOE issued a Funding Opportunity Announcement in August 2006, for two Bioenergy Research Centers, to be funded at $25 million each for five years. Under the President's Fiscal Year 2008 Budget Request, the number of Centers to be awarded was expanded to three and an additional $25 million per year was provided. The plan for the Bioenergy Research Centers represents a major reorientation of the original facilities plan for the Genomics:GTL program, with a new focus on energy and a new emphasis on the urgency of achieving mission-relevant scientific results in the bioenergy field.

- The Genomics:GTL program in the Office of Science's Biological and Environmental Research (BER) program supports advanced systems biology research on microbes and plants with a mission focus on breakthroughs in basic science needed to create new technologies for cost-effective bioenergy production, carbon sequestration, and environmental remediation.

- In August 2005, the GTL program set forth a detailed roadmap to develop and deploy four major scientific facilities for GTL. These four facilities were to be organized by function, with one each for production and characterization of proteins and molecular tags, characterization and imaging of molecular complexes, whole-proteome analysis, and analysis and modeling of cellular systems.

- In February 2006, a committee of the National Research Council (NRC) of the National Academies issued *Review of the Department of Energy's Genomics:GTL Program*. The NRC review praised the GTL program, recommending that the Department and the nation give "high priority" to GTL systems biology research. The panel, however, suggested a reorientation of the facilities plan. Rather than a succession of facilities organized around function, the NRC review recommended four research institutes. Each institute would incorporate, under a single roof, many or all of the technological capabilities planned for the original four facilities in a "vertically integrated" fashion as needed to achieve the institute's research goals.

- In response to the NRC report and President Bush's announcement of his Advanced Energy Initiative, the Office of Science in August 2006 issued a new Funding Opportunity Announcement for the creation and operation of two Bioenergy Research Centers to pursue the development of cost-effective cellulosic ethanol and other new biologically-based, renewable energy sources. Universities, national laboratories, nonprofit organizations, and private firms were invited to compete and encouraged to form partnerships or consortia to create and operate a center. The Department announced that it would provide $250 million in funding over five years ($25 million per year per center).

- Proposals were due on February 1, 2007. In February, with the submission of the President's FY 2008 Budget Request to Congress, the Department indicated that it would support the creation of a third Bioenergy Research Center, providing thereby a total of $375 million in funding over five years ($25 million per year per center).

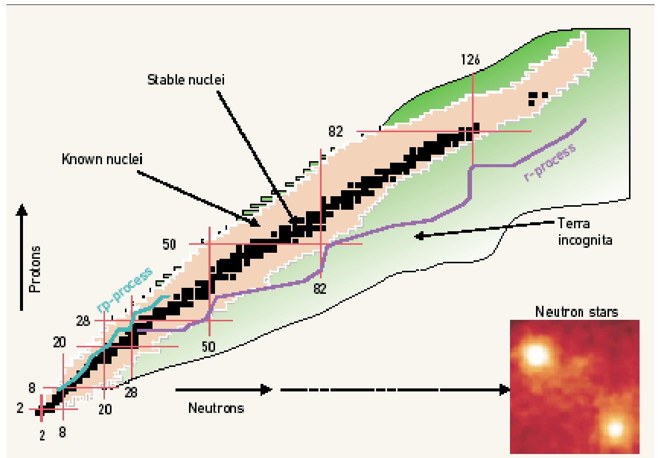
- Applications were evaluated by peer review, and selection of the three DOE Bionergy Research Centers was announced in June 2007. They include the DOE BioEnergy Science Center, led by the DOE's Oak Ridge National Laboratory in Oak Ridge, Tennessee; the DOE Great Lakes Bioenergy Research Center, led by the University of Wisconsin in Madison, Wisconsin, in close collaboration with Michigan State University in East Lansing, Michigan; and the DOE Joint BioEnergy Institute, led by DOE's Lawrence Berkeley National Laboratory.

- The Centers will bring together diverse teams of researchers from 18 of the nation's leading universities, seven DOE national laboratories, at least one nonprofit organization, and a range of private companies. All three Centers are located in geographically distinct areas and will use different plants both for laboratory research and for improving feedstock crops.

- The three DOE Bioenergy Research Centers are expected to begin work in 2008 and to be fully operational by 2009.

Priority: Tie for 3
Rare Isotope Accelerator (RIA) or Rare Isotope Beam Facility (RIBF)

For all the advances in our understanding of matter, we know comparatively little about the processes by which the heavier elements (those listed after iron in the Periodic Table) come to exist. The lightest elements, hydrogen and helium (with atomic numbers 1 and 2), were produced by the Big Bang. Elements up through iron (atomic number = 26) are manufactured in stars. Elements heavier than iron are believed to be synthesized by complex processes in exploding supernovae. Rare isotope beams give us the power to study these extraordinary astrophysical processes on earth, in the laboratory, and promise to vastly expand our understanding of nuclear astrophysics and nuclear structure. A rare isotope beam produces rare or exotic forms of the heavier elements—those with an unusual imbalance of protons and neutrons—that normally survive for only a small fraction of a second. These rare isotopes do not naturally exist on earth, but some are believed to arise in exploding supernovae and play a part in the synthesis of the heavier elements. Rare isotope studies will deepen our understanding of the nature of matter, and contribute to stockpile stewardship. Rare isotope beams also have potentially wide use in other fields: the isotopes they produce have advanced applications in materials science and medicine.



Nuclei with a large proton-to-neutron asymmetry are produced in stars and exhibit unusual properties.

Since early in this decade, the Office of Science has been planning to deploy a major new facility using rare isotope beams for nuclear physics research. In balancing priorities and taking into account facilities for rare isotope research that have been developed in other countries, the Office has modified its original plan for a Rare Isotope Accelerator.

Update: In response to budget constraints, and to avoid duplication of new isotope research capabilities emerging abroad (the Facility for Antiproton and Ion Research (FAIR) at the Institute for Heavy Ion Research (GSI) in Darmstadt, Germany), the Department revised its plans for implementing the Rare Isotope Accelerator (estimated cost of $1.1 billion) and proposes to construct a Rare Isotope Beam Facility at approximately half the cost of RIA. The planned RIBF would provide the United States with world-leading capabilities for rare isotope research, complementing the capabilities available internationally. The Department will issue a solicitation for design and siting of the RIBF in FY 2008 and plans to begin Project Engineering and Design on the facility around 2011.

- Rare isotope research remains an important priority for nuclear physics, with great promise for both illuminating critical mysteries of astrophysics (how the heavier elements are produced within stars and supernovae explosions) and discovering new structures of nuclei, with important applications to materials science, stockpile stewardship, and other fields.

- Accelerator R&D activities on rare isotope beam capabilities over the past several years have led to significant advances that have optimized machine performance and made possible a more cost-effective design for a Rare Isotope Beam Facility.

- In 2006, DOE and the National Science Foundation commissioned a study by the National Research Council (NRC) to define the science agenda for a next-generation U.S. facility for rare isotope beams. The NRC created a Rare Isotope Science Advisory Committee. In its report, the committee concluded that the DOE-planned RIBF would be "complementary" to existing and planned international efforts and should be a "high priority" for the United States.

- The Nuclear Science Advisory Committee was charged to establish a task force to perform an evaluation of the scientific "reach" and technical options for the RIBF. The Task Force Report submitted in FY 2007 identified the preferred technical option(s) and found that a world-class U.S. facility could be constructed at the reduced funding level.

- DOE continues to support R&D activities on rare isotope beam capabilities with a focus on optimizing machine performance, reducing technical risks, and optimizing costs.

Priority: Tie for 7
The 12 GeV Continuous Electron Beam Accelerator Facility (CEBAF) Upgrade

Despite the enormous progress we have made in understanding the sub-microscopic world of nuclear physics, much about the very core of the atom—the "nucleon," or the protons and the neutrons that make up the atomic nucleus—remains a mystery. In the 1960s, it was discovered that the proton and the neutron were not the most basic particles of matter but were each composed, in turn, of three subatomic particles that are called quarks. These quarks are held in confinement by the strongest of the fundamental forces of nature—the so-called strong interaction—a force with a strength some 10^{38} times that of the force of gravity. But much about how the strong interaction works—and the related question of how matter is held together at the most basic level—remains an enigma. There are three puzzles in particular: (1) How are the quarks confined inside the nucleon so that they can never be separated? (2) Why do the quarks provide only a small fraction of the total spin of the nucleon? and (3) Why do the three quarks provide only a miniscule component of the mass?

The 12 GeV CEBAF Upgrade includes the construction of a new experimental hall (Hall D). The Hall D subproject consists of building a new large acceptance detector for photon beam experiments that will search for so-called "exotic mesons," predicted by the theory of the strong interaction but so far not seen. Finding such particles would provide important information on how quarks are confined to form subatomic particles.

The Continuous Electron Beam Accelerator Facility at Thomas Jefferson National Accelerator Facility (TJNAF) is the most powerful facility in the world for probing for answers to these fundamental questions. The facility currently operates at an energy of about 6 giga-electron volts (GeV). The 12 GeV upgrade will double the capabilities of CEBAF. This will give scientists a history-making first glimpse into the very heart of the nucleon, providing the first three-dimensional images of the quarks within a nucleon. It may also provide the definitive evidence to explain the strong interaction.

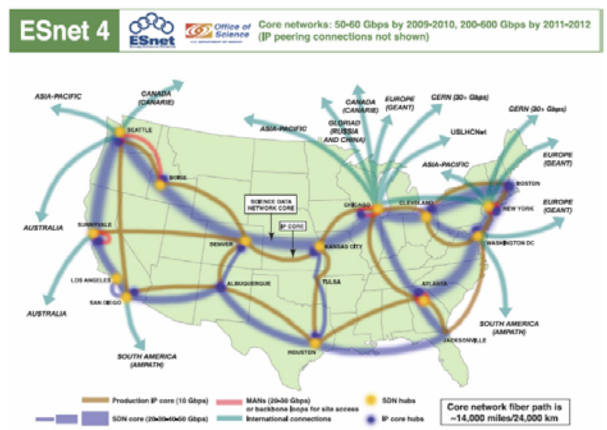
Update: Project Engineering and Design for the 12 GeV CEBAF Upgrade were initiated in FY 2006, and the project team is preparing to establish the project performance baseline in FY 2007. Construction could start in FY 2009 with project completion in 2015.

- The CEBAF at Thomas Jefferson National Laboratory is a world-leading facility for studies of the quark structure of matter. The proposed 12 GeV Upgrade will double CEBAF's beam energy from the current operating value of 6 GeV to 12 GeV to provide much more precise data on the structure of protons and neutrons. Specifically, the upgrade will enable scientists to address one of the great mysteries of modern physics—the mechanism that "confines" quarks together.

- The scientific program and technical concept of the 12 GeV Upgrade have been thoroughly reviewed by the Department of Energy's and National Science Foundation's Nuclear Science Advisory Committee, which recommended the 12 GeV Upgrade as one of its highest priorities in its 2002 Long-Range Plan.
- A 2005 DOE peer review of the science portfolio of the project concluded that the proposed program represented an impressive coherent framework of research directed towards one of the top frontiers of contemporary science: the exploration of confinement, a unique phenomenon of the Strong Interaction, one of the four fundamental forces of nature.
- Recent experimental results from CEBAF support the applicability of newly developed analytical techniques that could produce three-dimensional images of the internal structure of the nucleon, a major component of the planned upgrade scientific program.
- TJNAF is a world-leader in Superconducting Radio-Frequency (SRF) technology. TJNAF accelerator physicists have made innovative advances in the development of next-generation SRF accelerator cavities that will enable more compact and cost-effective machines not only for the 12 GeV Upgrade, but also for other future DOE accelerators.

Priority: Tie for 7
Energy Sciences Network (ESnet) Upgrade

When the Large Hadron Collider (LHC), the new particle accelerator being constructed at the European Center for Nuclear Research (CERN) in Switzerland, comes online, American scientists in laboratories and universities across the United States will have immediate access to the vast amounts of data being produced by detectors at the facility. This will enable hundreds of U.S. scientists to participate fully and directly in LHC research at their home institutions. This miracle of virtual collaboration on an international scale will be made possible by the Energy Sciences Network, a DOE-created network with massive bandwidth, linking researchers across the nation and around the world, enabling unprecedentedly seamless and effective collaboration and exchange of information among scientists working in diverse locations. In an era when scientific research is increasingly team-driven, ESnet facilitates collaboration in a host of different fields ranging from high energy physics to systems biology, to climate science, materials science, and chemistry. It leverages DOE investments throughout the complex.



The ESnet provides a high-speed and reliable communications network infrastructure that enables thousands of Department of Energy laboratory, university, and industry scientists and collaborators worldwide to make effective use of unique DOE research facilities and computing resources, independent of time and geographic location.

Update: The ESnet upgrade is in progress and on schedule. ESnet is completing a new architecture to provide 10 to 50 times the previous site bandwidths (depending on the particular site) connecting Argonne National Laboratory, Fermi National Accelerator Laboratory, and Brookhaven National Laboratory to the ESnet backbone to address critical requirements such as distribution of experimental data from the LHC at CERN in Switzerland. In 2008, ESnet plans to deliver a 10 gigabit per second (gbps) core Internet service as well as a Science Data Network with 20 gbps on its northern route and 10 gbps on its southern route. By the end of the decade, the partnership with Internet2 could enable ESnet to deliver between 160 and 400 gbps capability on its backbone.

- In 2004 and 2005, the first Metropolitan Area Network (MAN) was installed in the San Francisco Bay area to achieve high-bandwidth connectivity, guaranteed bandwidth services, and highly reliable network connectivity for DOE laboratories. Since then, MANs have also been completed in the Chicago area and Long Island, New York. These MANs will play a critical role in piping vast quantities of data from the LHC to U.S. scientists for analysis.
- The plan for the overall upgrade was successfully reviewed in February 2006, and was approved to proceed.

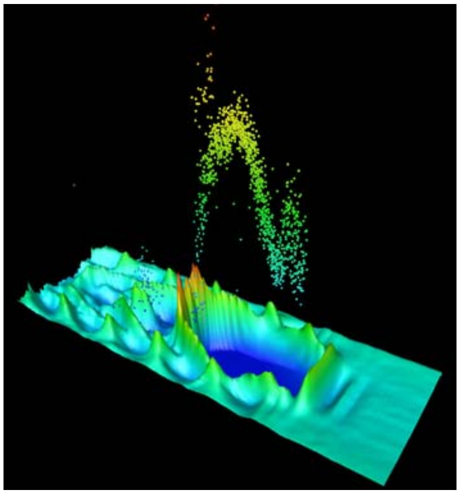
- In FY 2007 and beyond, ESnet will take advantage of its partnership with Internet2, which was announced in August 2006, to implement the next generation optical network infrastructure for U.S. science.

- By increasing bandwidth and supporting large-scale scientific collaborations across the nation, ESnet helps advance research not only in such basic science fields as high energy physics and chemistry, but also in such areas as climate change, genetics, renewable energy, nanotechnology, and national security.

Priority: Tie for 7
National Energy Research Scientific Computing Center (NERSC) Upgrade

NERSC at Lawrence Berkeley National Laboratory (LBNL) is the high-end computing facility with the largest scientific user base within the DOE complex.

As the premiere computational science facility, NERSC plays a major role in a wide range of discoveries—from predicting the properties of experimental nanostructures, to finding a surprising mechanism for supernova explosions that explains previously puzzling observations. As a partner in discovery, NERSC works with scientists to steadily expand the capabilities of scientific computation.



Plasma wave density and particle momentum distribution for a plasma wakefield accelerator, a project which could reduce the size of accelerators from kilometers to meters, making these tools more accessible for industrial and medical applications.

The results are based on simulations run on NERSC at LBNL through a 2006 Office of Science *Innovative and Novel Computational Impact on Theory and Experiment* (INCITE) program grant.

Update: NERSC capabilities continue their rapid growth. In 2004, the primary computing resource at NERSC was the 10 teraflop IBM Power 3+. To support users at NERSC, two mid-range high performance computing systems, a 3 teraflop Opteron cluster and an 8 teraflop IBM Power 5, were acquired in 2005 and 2006. Under the NERSC-5 request for proposals, NERSC awarded Cray, Inc. a $52 million contract to deliver a 100 teraflop Cray Hood system in January 2007.

- NERSC continues to provide high-end capacity computing to the entire DOE Office of Science research community. In 2005, NERSC users reported the publication of more than 1,200 papers that were based wholly or partly on work done at NERSC.

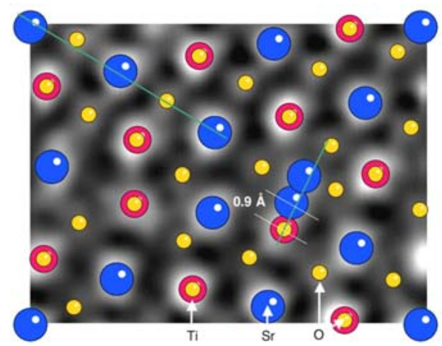
- A programmatic review of NERSC in May 2005 found that “NERSC is a strong, productive, and responsive science-driven center that possesses the potential to significantly and positively impact scientific progress by providing users with access to high performance computing systems, services, and analytics beneficial to the support and advancement of their science.”

- In June 2005, the NERSC Users Group published their report, *DOE Greenbook: Needs and Directions in High Performance Computing for the Office of Science*, which outlined the computational needs of future programs in the Office of Science.

Priority: Tie for 7
Transmission Electron Aberration Corrected Microscope (TEAM)

Electron microscopes were among scientists’ first tools for probing matter at the nanoscale. Yet as nanoscience has advanced, the performance requirements for electron microscopes have become ever more demanding. Achieving ever more precise resolution on ever smaller scales requires overcoming inherent aberrations in the operations of these devices that undermine performance. This in turn requires dramatic breakthroughs in electron optics, mechanics, and electronics—breakthroughs that are beyond the reach of any single university or laboratory.

Five national laboratories have teamed together to develop a new generation of electron microscope with the capability of sub-nanometer resolution. Based at Lawrence Berkeley National Laboratory, the team includes researchers from Argonne National Laboratory, Brookhaven National Laboratory, Oak Ridge National Laboratory, and the Frederick Seitz Materials Research Laboratory at the University of Illinois at Urbana-Champaign.



Atomic structure of a Sigma 13 grain boundary in SrTi03. TEAM will be the first of a new generation of intermediate-voltage electron microscopes capable of developing a much more fundamental understanding of materials by achieving resolution near 0.05 microns.

The TEAM microscope will have multiple applications to materials science and nanoscience to help scientists design new materials for everything from more efficient automobiles to stronger, more energy-efficient buildings, and new ways of harvesting energy.

Update: The TEAM project is proceeding as planned. TEAM has an approved Performance Baseline, and fabrication of an aberration-corrected electron microscope at Lawrence Berkeley National Laboratory for the materials and nanoscience communities will proceed on schedule, with an initial instrument available to users in FY 2008 and fabrication of the final instrument completed in FY 2009.

- Mission Need for the TEAM project was approved in June 2004, and the performance baseline was established in November 2006 along with the approval for start of fabrication.
- The TEAM instrument is expected to attain spatial resolution of 0.05 nm. Beyond sheer resolution, expected and planned improvements in sample manipulation, in-situ capabilities, signal-to-noise ratio, mechanical and electrical stability, and other aspects are also important instrumentation developments. They will greatly expand the capabilities of TEAM over existing electron microscopes, providing scientists with a world-leading tool for materials science and nanotechnology research.

Priority: 12
BTeV Experiment

BTeV was a project to build a new detector to use the Tevatron accelerator at Fermi National Accelerator Laboratory to study what is known as Charge Parity violation, relating to the imbalance between matter and anti-matter in the universe.

Update: The proposed BTeV experiment at Fermilab was terminated in early 2005.

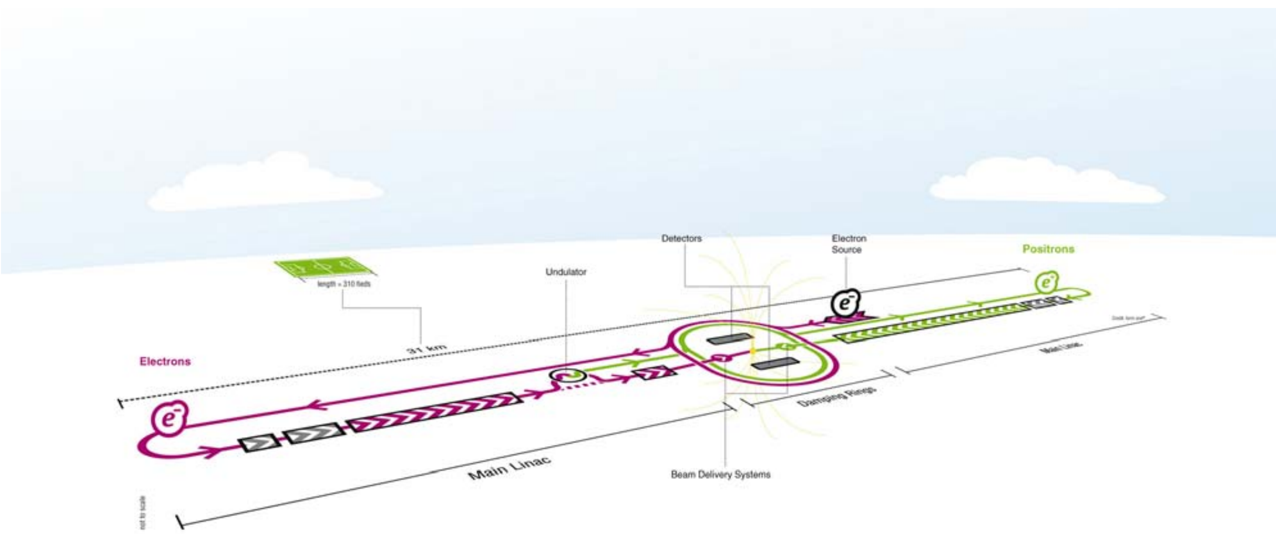
- In 2004, independent reviews were conducted of BTeV, including an evaluation of the physics plan by High Energy Physics Advisory Panel's Particle Physics Project Prioritization Panel (P5).
- In September 2004, P5 reiterated that BTeV would be a scientifically valuable experiment but that, in order to remain competitive with a similar experiment being constructed in Europe called the LHC-b, the completion date of the experiment could not be stretched out beyond the end of FY 2010. If for any reason (budget or technical), this schedule could not be met, P5 would not continue to support BTeV.
- The press of higher priorities, such as operations of particle physics user facilities at the Fermilab Tevatron and the Stanford Linear Accelerator (SLAC) B-Factory, as well as U.S. participation in the Large Hadron Collider (LHC), precluded including BTeV in the Department's planned program. This had the effect of delaying the completion date beyond FY 2010, leading to the termination of the proposed BTeV detector in early 2005.

Mid-Term Priorities

Priority: 13
International Linear Collider (ILC)

According to modern physics and cosmology, the universe began in a very dense, extremely high energy state with the Big Bang. The nature of the particles of matter and their interactions at this early moment dictated the character of our present universe. By colliding very high energy particles, particle accelerators provide a window into the sub-nuclear world, thereby serving as a "telescope looking backward in time" to the time of the Big Bang. The higher the energy of the particle collisions, the farther back in time scientists can "see."

Over the past fifty years, particle physicists have produced a far-reaching theory called the "Standard Model" that seems to describe the behavior of matter down to the level of tiny quarks and explains how all particles acquire mass through an as yet unobserved particle, the Higgs Boson. Yet the Standard Model has fundamental shortcomings, and physicists expect that it is only an approximation to a deeper theory. New particles, new forces of nature, or hidden dimensions of space and time are expected. Discovering the Higgs, or whatever new ingredients Nature has chosen, will dramatically improve our understanding of the building blocks of the universe, help explain the beginnings of the universe, and illuminate the nature of space, time, and matter.



A schematic layout of the International Linear Collider.

Update: The Department of Energy continues to support R&D toward the development of this next-generation electron-positron accelerator, to extend the scientific reach beyond the Large Hadron Collider (LHC) presently under construction at the European Center for Nuclear Research (CERN). A decision regarding the Department's path forward on the ILC awaits completion of further R&D, especially on the high-energy Superconducting Radio-Frequency (SRF) technology that would form the core technology of this proposed accelerator. Evaluation of the science potential of the ILC will require an analysis of early results at the LHC, expected in 2010-2011.

- In April 2006, a National Research Council committee issued a report on the future of elementary particle physics in the United States (*Revealing the Hidden Nature of Space and Time*), recommending substantial U.S. investments in R&D for the ILC to lay the groundwork for a possible decision to host the ILC at Fermi National Accelerator Laboratory in the United States.

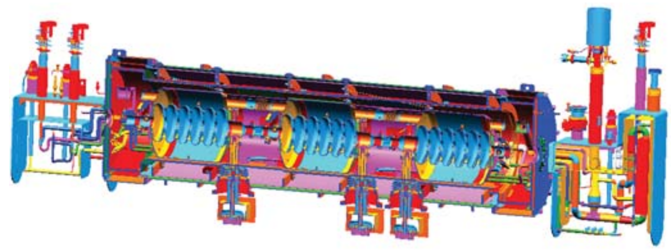
- In February 2007, the Global Design Effort (GDE), an international team conducting the R&D and conceptual design for the accelerator, issued a Reference Design Report for the ILC.

- Following the issuance of this Reference Design Report, the GDE indicated that determining SRF technology feasibility at the required energy levels would take from three to five years.

- The Department continues to support R&D on SRF technology because of its applicability not only to ILC, but also to the development of a new generation of particle accelerators for science, medicine, and industry.

Priority: Tie for 14
Spallation Neutron Source (SNS) 2-4 MW Upgrade

Neutron scattering research is one of the most powerful tools that scientists have to understand, predict, and improve the properties of materials. It has been used to create major improvements in products across the entire U.S. industrial base, in industries as diverse as pharmaceuticals, food processing, electronics, and transportation. The Spallation Neutron Source at Oak Ridge National Laboratory will provide the most intense pulsed neutron beams in the world for scientific research and industrial development. As the world's most powerful pulsed neutron source, SNS has important implications not only for science, but also for U.S. economic competitiveness. The SNS will give U.S. scientists and industry a substantial lead over their international counterparts in this crucial capability of modern materials science and nanoscience.



The SNS Upgrade will support a second neutron beam, target station, and associated suite of instruments, doubling the number of researchers who can use the facility. The linac tunnel is sized for nine additional "cryomodules," such as the one above.

Planning is already underway for a follow-on upgrade of the power of the SNS, construction of which was completed in June 2006.

Update: The SNS Power Upgrade Project (PUP), promising to double the proton beam power capability of this world-leading neutron beam facility at Oak Ridge National Laboratory, is on schedule to obtain approval for the preliminary baseline range in mid-FY 2007, leading to possible completion of the PUP project in 2012.

- The conceptual design for PUP was reviewed in May 2006. R&D efforts on the two technical challenges for the project, the mercury target and front end systems, are underway. Recent R&D results have been promising.

- Additional R&D efforts are being conducted through collaboration with international partners in Japan and Europe, as well as through direct funding of research at U.S. universities, laboratories, and industrial partners.

- With work underway on twenty of the twenty-four instrument stations at SNS, instrument build-up has advanced faster than originally anticipated. This means that the opportunity to take advantage of the advanced performance provided by the Power Upgrade Project is even greater than originally planned.

- Progress on building neutron source facilities in Japan (J-PARC), China (CSNS), and Europe (ISIS Second Target Station) makes the case for proceeding with the power upgrade even more compelling to secure U.S. leadership in this field for the foreseeable future.

Priority: Tie for 14
Spallation Neutron Source (SNS) Second Target Station

Planning is underway to update the technical concept for the SNS Second Target Station (STS2), taking into account the new higher-power capabilities that will be available with the completion of the Power Upgrade Project.

The SNS Second Target Station is designed for the study of large structures such as polymers, as well as biological materials including cell walls and membranes.

The second target station at the SNS will provide a long wavelength neutron source optimized for the study of large structures such as polymers and biological materials, including cell walls and membranes.

Update: The goal is to produce a report by Fall 2007 that documents these activities and conclusions in a manner that can be used to support a request for approval of Mission Need in FY 2008. Three workshops were held in 2006-2007 to follow a logical progression from STS2 scoping to neutronics to instrumentation.

- The first was a scoping workshop to define the most appropriate general focus for the STS2. The workshop took into account the priorities of the National Nanotechnology Initiative and the expected design of target stations at other facilities, including proposals for the European Spallation Source and the ISIS Second Target Station at the Rutherford Appleton Laboratory in the U.K.

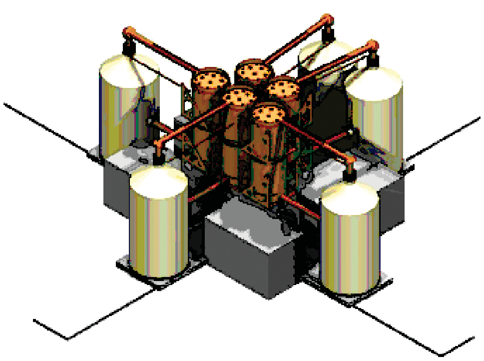
- The second workshop involved target station experts and was aimed at defining an appropriate concept for the target-moderator arrangement as a basis for further study by the SNS neutronics group. This workshop provided good guidance for appropriate target station configuration.

- The third, an instrumentation workshop, developed a concept for a suite of neutron beam instruments appropriately matched to source performance. This preliminary instrument suite will be further evaluated to show what kind of scientific performance could be offered by each of the instruments.

- The demand for cold neutron beams at STS1 has exceeded expectations. There are only three unallocated instrument positions remaining, with four requests for these currently in the pipeline. Hence, there is a strong incentive to proceed with STS2 as rapidly as is practical.

Priority: Tie for 18
Double Beta Decay Underground Detector

One of the most significant developments in nuclear and particle physics in the last several years is convincing evidence from a number of experiments that neutrinos have mass and transform from one type into another type: they oscillate between neutrino states. These experiments, however, only establish the difference in the masses of different types of neutrinos, and not each of their absolute masses. If the neutrino is its own antiparticle, then the best determination of the mass is expected to come from a measurement of neutrino-less double beta decay.



Artist's conception of one particular neutrino-less double beta decay experiment—the Majorana.

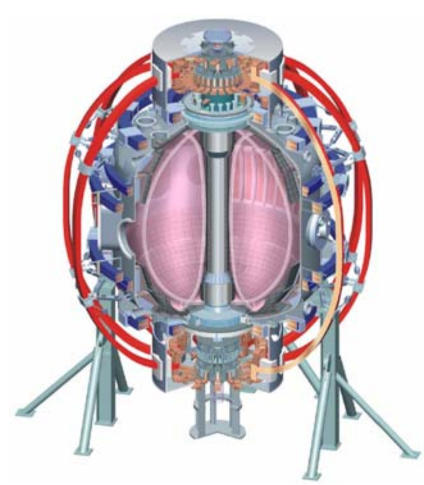
Update: In November 2005, the Department of Energy approved Mission Need for the Neutrino-less Double Beta Decay Project. University and laboratory researchers have been engaged in R&D activities for three candidate experiments, each based on a different technology: the Cryogenic Underground Observatory for Rare Events (CUORE), Majorana, and the Enriched Xenon Observatory (EXO). U.S. involvement in the Italian CUORE experiment is proposed to initiate fabrication activities in FY 2008, while R&D continues for the Majorana experiment to provide input into a technology choice for a future large international effort. A miniature prototype of the EXO experiment is now completed and will soon begin to take data. This prototype will set the path for possible fabrication of a larger experiment in the next decade.

- Mounting next generation neutrino-less double beta decay experiments was identified as one of the top scientific priorities of the American Physical Society 2004 report, *The Neutrino Matrix*.

- The DOE Offices of Nuclear Physics and High Energy Physics and the National Science Foundation Division of Physics requested that their advisory panels establish a Neutrino Scientific Assessment Group (NuSAG) to provide the agencies advice concerning the U.S. neutrino physics program, including neutrino-less nuclear double beta decay. The NuSAG recommended that the agencies pursue multiple double beta decay experiments with a phased approach and identified the three experiments mentioned above as priorities.

Priority: Tie for 18
Next-Step Spherical Torus (NSST)

The key to harnessing abundant, environmentally friendly fusion energy for electricity production lies in developing the means to sustain and contain a burning plasma whose temperature can exceed 100 million degrees Celsius. The main approach that scientists have pursued to date is the so-called tokamak design, which produces a doughnut-shaped magnetic field. This is the design that will be used for ITER. But there are some indications that an alternative design, the so-called spherical torus, might be more cost-effective in the long run.



Drawing of the NSST, which will test the performance of the spherical torus in a self-sustaining fusion reaction.

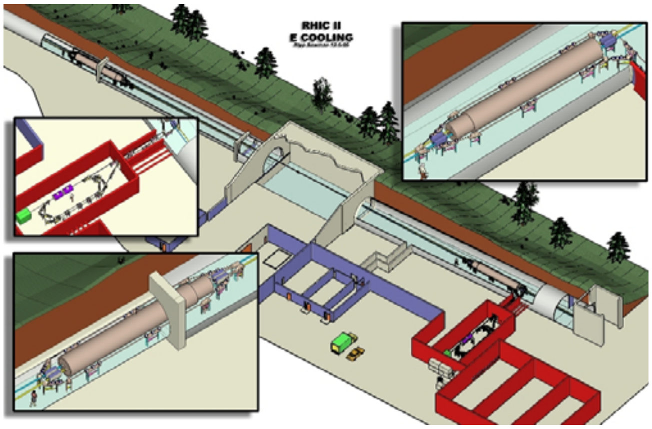
Update: Princeton Plasma Physics Laboratory is carrying out design scoping studies for a new, low-aspect-ratio experimental device, using a spherical torus, as opposed to a tokamak, to contain a fusion reaction. The Fusion Energy Sciences Advisory Committee (FESAC) will evaluate research priorities and needed facilities for the next twenty to twenty-five years. An initial report from FESAC on research priorities is expected in late 2007. A Next-Step Spherical Torus-style device could be one of the proposed facilities.

- Recent results from the National Spherical Torus Experiment (NSTX) demonstrate that using Coaxial Helicity Injection (CHI) for generating toroidal current in a plasma works well in larger facilities. This result is important for future fusion experiments such as NSST, because there will be little room for a solenoid sufficient to generate needed plasma current in future larger-scale spherical torus experiments.

- A successful research program on this device could lead to the construction of a reduced-cost Component Test Facility, providing the U.S. with unique worldwide capability to develop components for a demonstration fusion power plant.

Priority: Tie for 18
Relativistic Heavy Ion Collider (RHIC) II

Researchers at Brookhaven National Laboratory's Relativistic Heavy Ion Collider are pushing the frontiers of human knowledge by using a powerful particle accelerator to recreate conditions as they existed in the universe just microseconds after the Big Bang. In a headline-making development, RHIC has identified a new and entirely unexpected form of matter, a "perfect liquid" composed of quarks and gluons, the tiny components that make up the core of atoms. Work at RHIC will provide scientists with a deeper fundamental understanding of nuclear matter and its interactions.



A three-dimensional view of the electron cooler and part of the RHIC tunnel. Electron cooling is a method to reduce the beam size in ion storage rings. "Cold" electrons are used to cool the "hot" ion beam. The result of cooling is a smaller beam size, a higher particle density, and therefore higher luminosity.

RHIC accelerates two beams of gold nuclei to high energies and brings them into head-on collisions inside state-of-the-art detectors designed to observe the particles that emerge. The collision disintegrates the nuclei and momentarily produces the unimaginably hot and dense matter called the quark-gluon plasma.

Update: RHIC II would provide a tenfold increase in beam luminosity at the Relativistic Heavy Ion Collider at Brookhaven National Laboratory. RHIC has been making headlines with its discoveries about the strange nature of matter in the very early universe. R&D activities continue with a focus on demonstrating the technical feasibility of increasing beam luminosity through "electron cooling" of RHIC's high energy ion beams. The pace of R&D is such that the RHIC II project will be in a position to start construction within the next five years.

- At RHIC, the conditions of the early universe were recreated in heavy ion collisions. Researchers have discovered a new state of hot, dense matter that behaves like a "perfect liquid," rather than a fiery gas of quarks and gluons that had been predicted. The RHIC II upgrade could provide further insights into this strange newly discovered state of matter.

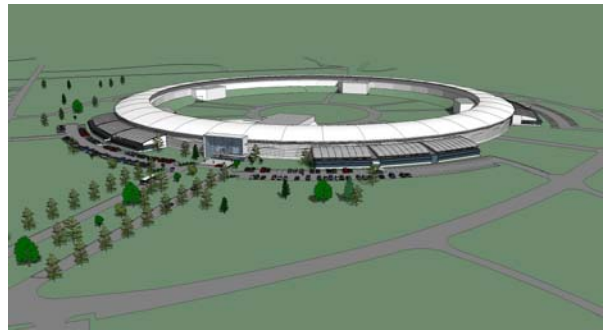
- Advanced computer simulations of the proposed electron cooling process and R&D activities of technical options, coupled with advances in beam cooling techniques, have led to a refinement of the RHIC II project design, including technical choices that have reduced technical risks and made the design more cost-effective.

- Modest upgrades to the two major detectors at RHIC, STAR, and PHENIX, have been ongoing for several years. They are not only important for ongoing research at RHIC, but also essential for preparing the detectors for the RHIC II science portfolio as well.

Far-Term Priorities

Priority: Tie for 21
National Synchrotron Light Source II (NSLS-II)

The National Synchrotron Light Source at Brookhaven National Laboratory is one of several high-intensity light sources in the DOE complex that enable scientists to study matter at the atomic scale. Over 2,300 researchers from universities, national laboratories, and industry use the NSLS each year. The NSLS has aided discovery in a staggering array of fields. Progress toward new detection methods for breast cancer and osteoarthritis, steps toward possible eventual development of a vaccine for HIV and AIDS, the development of more powerful microchips and more efficient hard drives, and research toward reducing pollution by improving catalytic converters—these are only a handful of the areas in which the NSLS has accelerated scientific progress. NSLS-II will provide a major upgrade over the NSLS's current capabilities, delivering 10,000 times the brightness and nanometer-scale resolution and an energy resolution of 0.1 millielectron volt (1°k) .



Artist's drawing of the NSLS-II, the first of the next-generation of synchrotrons, which will be brighter, more stable, easier to use, and will accommodate many new types of experiments.

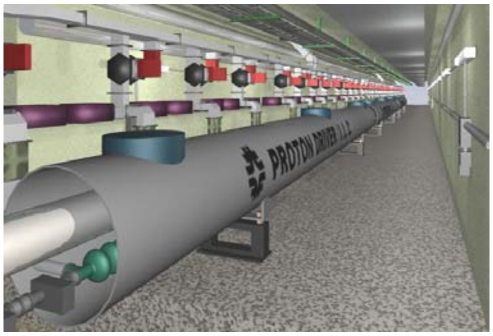
Update: In the 2003 *Facilities for the Future of Science: A Twenty-Year Outlook*, NSLS-II was given a perfect score in the "scientific merit" criterion but placed among the "Far-Term Priorities," based on a lower score on the "readiness-to-proceed" criterion. The NSLS-II project team submitted a revised proposal in 2004; the proposal was peer reviewed by scientific leaders in the field worldwide, and a panel of accelerator experts reviewed its technical design. As a result of very positive reviews, DOE decided to accelerate the project to a Near-Term Priority. Mission Need for NSLS-II was approved in August 2005. The Department has approved Critical Decision (CD-1) for the National Synchrotron Light Source II (NSLS II) project at the Brookhaven National Laboratory (BNL). Project Engineering and Design will be initiated in FY 2007, and construction could begin in FY 2009, with commissioning of the facility around FY 2014.

- The NSLS-II project will set a new standard for storage-ring-based light sources. The NSLS-II is proposed as a new synchrotron light source, highly optimized to deliver ultra-high brightness and flux and exceptional beam stability. It would also provide advanced insertion devices, optics, detectors, robotics, and an initial suite of scientific instruments.

- NSLS-II would be the best storage-ring-based synchrotron light source in the world. More importantly, NSLS-II would be transformational, opening new regimes of scientific discovery and investigation. It will be the first light source that combines nanometer spatial resolution with high brightness, coherence, and beam stability, enabling routine nanometer-scale characterization of materials, with powerful applications to biotechnology, nanotechnology, and the study of materials under extreme conditions.

Priority: Tie for 21
Super Neutrino Beam

The philosopher Martin Heidegger once posed the question, "Why are there beings at all rather than nothing?" Modern physics puzzles over a similar problem. If Nature obeyed the laws of symmetry, equal quantities of matter and anti-matter would have been created at the Big Bang, and these equal quantities should have mutually annihilated one another to produce nothing but energy. But our universe exists, and seems to consist of matter (rather than anti-matter) as far as the eye (or the other instruments we have available) can see, so there must be a curious asymmetry built into nature. This asymmetry is called Charge Parity (CP) violation. One of the most promising areas for studying CP violation lies in the oscillation of neutrinos, but our ability to create a facility to detect this oscillation depends on a value called the neutrino mixing angle that we do not know yet .



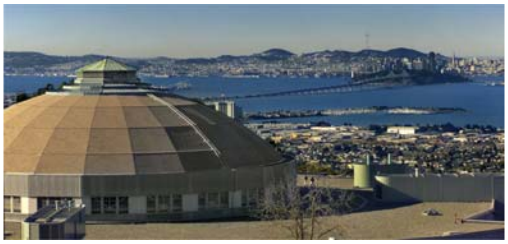
The Super Neutrino Beam will allow more comprehensive studies of neutrino properties by producing an intense, well-controlled beam with 10 times more neutrinos per second than are available from any existing facility—to detectors hundreds or thousands of miles distant. Results will have profound implications for our understanding of the fundamental properties of matter and the evolution of the early universe.

Update: The Neutrino Scientific Assessment Group (NuSAG), a subpanel of the High Energy Physics Advisory Panel, will reexamine the physics case for a super neutrino beam as more becomes known about the neutrino mixing angle from a first round of experiments that are about to begin fabrication. The value of the neutrino mixing angle will determine the type of facility required to effectively study questions of Charge Parity (CP) violation in the neutrino sector. If the value of the neutrino mixing angle is large enough, then incremental upgrades to the existing neutrino beam facilities such as the Neutrinos at Main Injector (NuMI) at Fermilab (FNAL) may be an attractive option. If the neutrino mixing angle is too small, then a super neutrino beam could be insufficient to address the questions of CP violation in the neutrino sector.

- The October 2006 Particle Physics Project Prioritization Panel (P5) roadmap for the future of particle physics recommended a phased program in neutrino physics. This program will first pursue measurements of the neutrino mixing angle and then study the hierarchy of neutrino masses.
- The first phase of the program can be carried out with new experiments at reactors, the existing accelerator-based neutrino experimental facilities, and the J-PARC facility under construction in Japan. Results from these experiments will provide crucial information to help further define a megawatt-class super neutrino beam to study CP violation in the neutrino sector.
- R&D activities continue at a modest level with a focus on technical demonstration of prototype accelerating components compatible with the accelerating structures of the International Linear Collider design.

Priority: Tie for 23
Advanced Light Source (ALS) Upgrade

The Advanced Light Source at the Lawrence Berkeley National Laboratory is one of the world's brightest sources of ultraviolet and soft x-ray beams—and the world's first third-generation synchrotron light source in its energy range. The ALS produces light in the x-ray region of the electromagnetic spectrum that is one billion times brighter than the sun. The ALS offers unprecedented opportunities for state-of-the art research in materials science, biology, chemistry, physics, and the environmental sciences. Ongoing research topics include the electronic structure of matter, protein crystallography, ozone photochemistry, x-ray microscopy of biological samples, and optics testing. About 2,000 researchers make use of this facility each year.



The ALS Upgrade will make the facility applicable to an even broader range of forefront research areas to help solve our Nation's critical energy needs.

Update: The Basic Energy Sciences Advisory Committee currently is engaged in a study of Grand Challenge Science that spans all of the research supported by the Basic Energy Sciences program. An outcome of this study will be the delineation of research frontiers and the tools required to access those frontiers.

- The future upgrade paths and/or a replacement facility for the ALS at Lawrence Berkeley National Laboratory are being considered.

- One option is a next-generation light source based on a seeded, high-repetition-rate free electron laser facility, operating in the vacuum-ultraviolet to soft x-ray wavelength range. Such a facility would permit the direct quantitative measurements of electronic and atomic structure with ultrahigh spectral resolution and structural dynamics on an ultrafast time scale, capabilities that are important for studying complex systems and correlated phenomena in atoms, molecules, and complex solids.

Priority: Tie for 23
Advanced Photon Source (APS) Upgrade

The Advanced Photon Source at Argonne National Laboratory is the brightest x-ray light source in the Western Hemisphere. These x-rays allow scientists to study the structure and function of materials. Knowledge gained from this research can impact the evolution of combustion engines and microcircuits, aid in the development of new pharmaceuticals, and pioneer nanotechnologies whose scale is measured in billionths of a meter, to name just a few examples. These studies already have had far-reaching impact on our technology, economy, health, and fundamental knowledge of the materials that make up our world. The Advanced Photon Source has the largest user base of any DOE scientific user facility, with 3,200 scientists from academia, industry, and government using it annually.


The APS Upgrade will greatly enhance the brilliance and power of the facility to enable scientists to study very small sample crystals—important for nanoscience research.

Update: The Basic Energy Sciences Advisory Committee currently is engaged in a study of Grand Challenge Science that spans all of the research supported by the Basic Energy Sciences program. An outcome of this study will be the delineation of research frontiers and the tools required to access those frontiers.

- One option being considered to upgrade the APS is through an energy-recovery linac (ERL). The ERL has been demonstrated at lower energy, but research and development of improved electron guns and superconducting linear accelerator technology is required. With sufficient R&D in the coming years, it could be possible to design and build an APS upgrade in the next decade.

Priority: Tie for 23
eRHIC, eLIC, or the Electron Ion Collider (EIC)

Nuclear physics seeks a deeper understanding of the forces that hold matter together at the most basic level—the mysterious interactions of quarks and gluons that constitute the nucleons (proton or neutron) at the core of the atom. Penetrating the mystery of the nucleon will require bombarding the nucleon at ever higher energies.

Update: Since the development of the concept for eRHIC as an upgrade to the Relativistic Heavy Ion Collider (RHIC) at the Brookhaven National Laboratory, an alternative conception has emerged for an Electron Light Ion Collider (eLIC), which would be an upgrade to the Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility. Both concepts would involve collisions between protons or ions, on the one hand, and electrons, on the other. These collisions could provide breakthrough insights into Quantum Chromodynamics (QCD), which studies the behavior of quarks and gluons in the nucleus. The Nuclear Science Advisory Committee's new five-year plan for the field of Nuclear Physics, currently under deliberation, will include consideration of both eRHIC and eLIC, the two alternative concepts for the EIC.

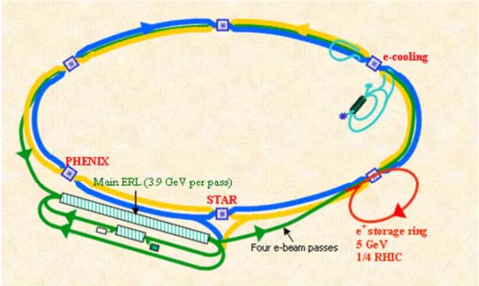
- These proposed facilities would be designed for unprecedented studies of both the polarization of the gluons in the nucleon and the role of quarks and gluons in the nuclei. Understanding of these scientific topics will have direct consequences for the understanding of QCD in extreme conditions and bring fundamental insight to recent discoveries at RHIC.

- The concept of the eRHIC facility at the Brookhaven National Laboratory is based on the existing RHIC, with the addition of an intense electron beam, to provide electron-proton and electron-ion collisions.

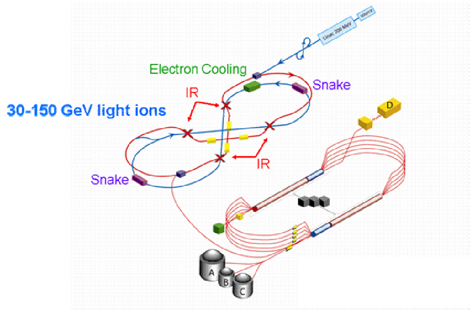
- The eLIC concept relies on the CEBAF accelerator being upgraded to 12 GeV to feed a new electron storage ring and the addition of a new proton and light ion beam complex to provide electron-ion collisions.

- To achieve stated luminosities of either option, electron cooling of ions is essential, and proton cooling is required by some of the technical options under consideration. R&D activities conducted over the past several years, including the development of an innovative electron beam cooling system at RHIC, are expected to demonstrate the feasibility of increasing the luminosity of the colliding beams by a factor of 10 to 30.

- R&D efforts are expected to continue at university centers and national laboratories to demonstrate technical feasibility of the proposed project and to develop the most cost-effective design with the highest scientific reach.



Schematic layout of the electron ERL linac ring and the ion ring, the "linac-ring" option of eRHIC.

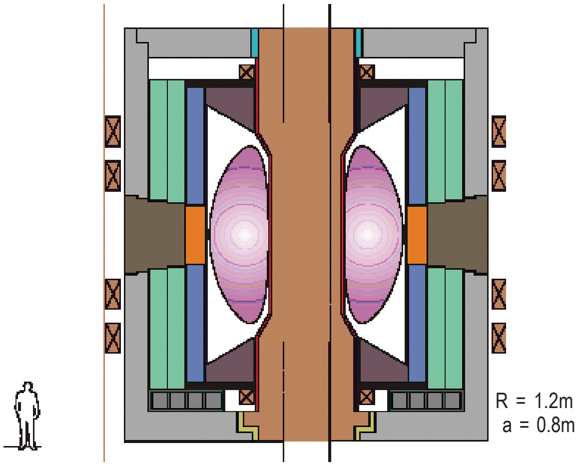


Schematic layout of the electron ERL linac ring and the ion ring for eLIC.

Priority: Tie for 23
Fusion Energy Contingency

The objective of the Fusion Energy Contingency would be to develop the test power plant components and materials that will be needed to complete the process of making fusion energy a viable commercial energy resource by mid-century.

Update: Since the 2003 publication of *Facilities for the Future of Science: A Twenty-Year Outlook*, there has been no R&D or design performed to develop further the details of this facility. If built, this facility would complement the research program to be conducted at ITER.



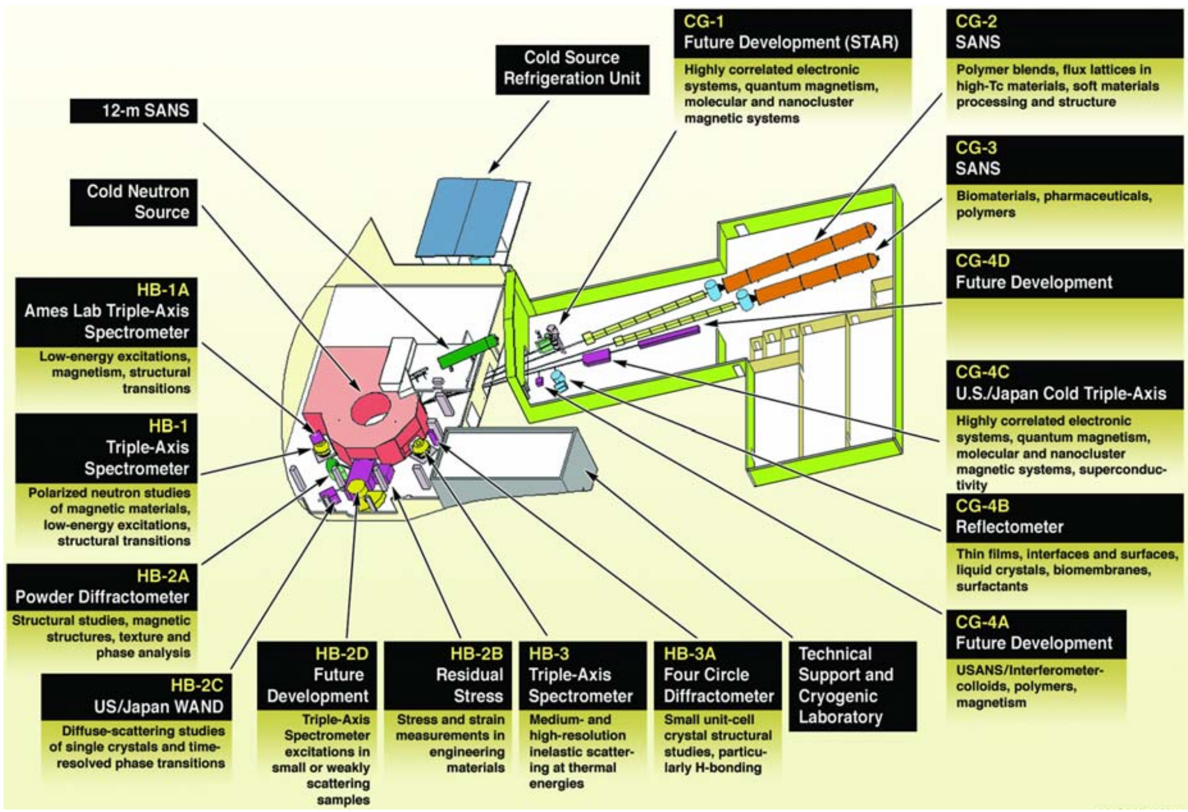
The Component Test Facility will qualify materials and components for use in fusion demos.

- A system study to develop the key parameters of the facility was started in FY 2007.

- The system study is expected to be completed in FY 2009. Further work will depend on the outcome of the study, as well as the results from the recent charge given to the Fusion Energy Sciences Advisory Committee to determine the "research gaps" in the program and how they should be filled to propel the U.S to scientific leadership.

Priority: Tie for 23
High-Flux Isotope Reactor (HFIR) Second Cold Source and Guide Hall

Neutron-scattering research, one of the most powerful techniques that scientists have today for understanding and improving the properties of materials, was developed at Oak Ridge National Laboratory (ORNL) in the 1950s. Along with hosting the Spallation Neutron Source, soon to be the world's most powerful source of *pulsed* neutron beams, ORNL has been home since 1966 to the High-Flux Isotope Reactor, one of the world's most powerful sources of steady-state neutron beams. Plans are underway to expand HFIR's capabilities to accommodate a growing community of researchers.



This diagram shows the present layout of instruments at HFIR. A second cold source and Guide Hall at the HB-2 beam line would replace current instruments and be located at the following positions in the above diagram: HB-2A, HB-2B, HB-2C, and HB-2D.

Update: Following the commissioning of the first cold source and Guide Hall using the HB-4 beam port at HIFR at Oak Ridge National Laboratory (ORNL), a two- to three-year effort will be needed to complete conceptual evaluations and planning for a second Guide Hall making use of the HB-2 beam port. The goal is to perform conceptual studies and planning necessary to support a HB-2 project start. With an anticipated five-year project, this would make the facilities available in the future.

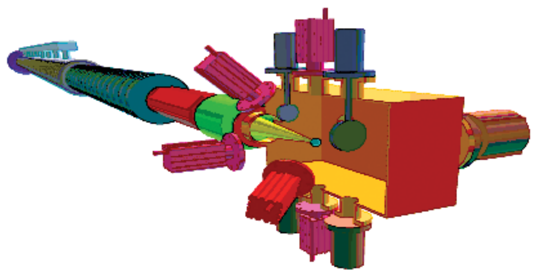
- With the completion and successful testing of the first cold source and Guide Hall using the HB-4 beam line at HFIR, the ORNL team is prepared to address the heat flux and background issues presented by building a second cold source at the HB-2 beam line. This second cold source could provide cold neutron beams at sample locations nearly an order of magnitude better than the best steady-state cold neutron beams in the world.

- The HB-2 beam line is large enough to support five large neutron beams that could translate to as many as nine neutron instrument stations in the Guide Hall and potentially specialized facilities beyond the Guide Hall.

- The focus in the short term at HFIR is the operation of the HB-4 cold source and the installation and commissioning of additional Guide Hall instruments. In addition, HFIR is roughly half finished with its life extension program, which involves updating key technical systems and infrastructure and which will allow the reactor to operate until 2040 with only one major shutdown in 2021 for a Beryllium reflector change.

Priority: Tie for 23
Integrated Beam-High Energy Density Physics Experiment (IB-HEDPX)

High energy density physics is the study of matter under conditions of extremely high temperature and densities and encompasses areas ranging from astrophysics to laboratory plasma physics.



An IB-HEDPX capability for integrated acceleration compression and focusing on high current, space-charge-dominated beams would be unique—not available in any existing accelerator in the world.

Update: Mission Need for the IB-HEDPX (formerly called the Integrated Beam Experiment, or IBX), an intermediate-scale experiment using heavy ion beams for research on Warm Dense Matter (a midway state between solid matter and plasmas), was approved by the Department in 2005. Small-scale experiments are planned in 2008-2009 as part of R&D to provide a scientific basis for the new facility.

- Two National Academy of Sciences reports identified high energy density physics (HEDP) as a compelling emerging science for the Nation. In 2004, a community-based National Task Force on HEDP developed a science-driven roadmap for a National Initiative in HEDP. One of the fifteen "Thrust Areas" identified in the roadmap includes research in Warm Dense Matter driven by heavy ion beams.

- The fundamental requirements for using heavy ion beams in Warm Dense Matter research include compression of the beam, focusing of the beam, and high repetition rates. These critical scientific issues for developing IB-HEDPX have been resolved.

- The Office of Science Fusion Energy Sciences program and the National Nuclear Security Administration have created a new joint program in High Energy Density Laboratory Plasmas to advance this and related research. In addition, there is a broad international community engaged in this research, with which U.S. scientists coordinate activities.

About DOE's Office of Science

The U.S. Department of Energy's Office of Science is the single largest supporter of basic research in the physical sciences in the United States, providing more than 40 percent of total funding for this vital area of national importance. It oversees—and is the principal federal funding agency of—the Nation's research programs in high-energy physics, nuclear physics, and fusion energy sciences.

Brookhaven National Laboratory's Relativistic Heavy Ion Collider

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The Office of Science manages this research portfolio through six interdisciplinary program offices: Advanced Scientific Computing Research, Basic Energy Sciences, Biological and Environmental Research, Fusion Energy Sciences, High Energy Physics, and Nuclear Physics. In addition, the Office of Science sponsors a range of science education initiatives through its Workforce Development for Teachers and Scientists program.

Thomas Jefferson National Accelerator Facility

The Office of Science makes extensive use of peer review and Federal advisory committees to develop general directions for research investments, to identify priorities, and to determine the very best scientific proposals to support.

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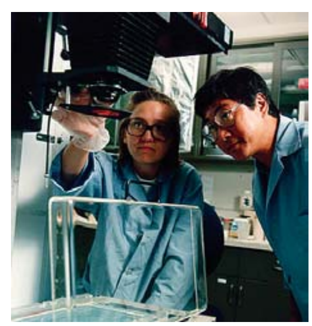

Microbiologists at the Pacific Northwest National Laboratory

The Office of Science is a principal supporter of graduate students and postdoctoral researchers early in their careers. About a third of its research funding goes to support research at more than 300 colleges, universities, and institutes nationwide.

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To attract and encourage students to choose an education in the sciences and engineering, the Office of Science also supports the National Science Bowl®, an educational competition for high school and middle school students involving all branches of science. Each year, DOE's National Science Bowl® attracts more than 17,000 students nationwide. At the high school level, it involves more than 12,000 students, and at the middle school level, more than 5,000 students.

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