Advanced Scientific Computing Research

Funding Profile by Subprogram

(dollars in thousands)

	FY 2009 Current Appropriation	FY 2009 Current Recovery Act Appropriation[a]	FY 2010 Current Appropriation	FY 2011 Request
Advanced Scientific Computing Research				
Mathematical, Computational, and Computer Sciences Research	150,373	+37,130	163,792	165,091
High Performance Computing and Network Facilities	208,399	+124,665	230,208	260,909
Total, Advanced Scientific Computing Research	358,772[b]	+161,795	394,000	426,000

Public Law Authorizations:
Public Law 95–91, "Department of Energy Organization Act", 1977
Public Law 108–423, "Department of Energy High-End Computing Revitalization Act of 2004"
Public Law 109–58, "Energy Policy Act of 2005"
Public Law 110–69, "America COMPETES Act of 2007"

Program Overview

Mission

The mission of the Advanced Scientific Computing Research (ASCR) program is to discover, develop, and deploy computational and networking capabilities to analyze, model, simulate, and predict complex phenomena important to the Department of Energy (DOE). A particular challenge of this program is fulfilling the science potential of emerging multi-core computing systems and other novel "extreme-scale" computing architectures, which will require significant modifications to today's tools and techniques.

Background

Imagine exploring the inner workings of a supernova or traveling through time to observe Earth's global climate as it changes. Scientists today can explore these realms thanks to a 100 fold increase in computing power delivered over the past five years and to the software developed to harness the power of these forefront computers.

Throughout history, as we have strived to comprehend the mysteries of the universe, mathematics has been an essential tool. It allowed Pythagoras to determine the diameter of the earth. Newton and Leibniz invented calculus to understand the movement of the planets. Mathematical research in the 1800s led to Einstein's Theory of General Relativity.

While mathematics enabled the study of increasingly complex problems, the time to carry out these calculations became unmanageable. Today, advances in mathematics and computing enable scientists to gain new insights into societal concerns such as Alzheimer's disease and climate change. ASCR and its predecessor programs have led these advances for the past thirty years.

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[a] The Recovery Act Current Appropriation column reflects the allocation of funding as of September 30, 2009.
[b] Total is reduced by $10,048,000: $8,972,000 of which was transferred to the Small Business Innovation Research (SBIR) program and $1,076,000 of which was transferred to the Small Business Technology Transfer (STTR) program.

In FY 2009, ASCR delivered petascale computing power to the open science community and two of the world's fastest computers for open-science. These machines enabled two Gordon Bell prizes, including the world's first petascale application, and swept the High Performance Computing challenge at SuperComputing08—an international conference on high performance computing with about 11,000 participants and a technical program that has included breakthroughs in many areas and inspired new and innovative areas of computing. At SuperComputing09, ASCR's Oak Ridge Leadership Computing Facility topped the list of the "Top 500" computers in the world and added another Gordon Bell prize. Since the machines are open to all on a competitive basis, the scientific applications span a variety of topics such as: flame simulation to guide design of fuel-efficient clean engines, high temperature superconductivity, supernova shock wave instability, designing proteins at atomic scale, and creating enzymes.

Computational scientists create mathematical models and simulations of physical, biological, and chemical phenomena, which allow them to better understand the phenomena and to predict behavior. In the case of climate change, there is a growing demand for the development of tools that will help inform decision makers on the options for addressing and adapting to a changing climate. Waiting for the observation and recording of the impacts of increasing concentrations of greenhouse gases is not sufficient. With computation and simulation, scientists can model what is known about the Earth's systems, identify uncertainties of the models, and determine the observational data and experiments needed to further refine and improve the models. Improved climate models will allow scientists to predict, with greater confidence, future changes in the climate under various scenarios. These modeling efforts can help identify potential mitigation strategies.

ASCR supports basic research in both applied mathematics and computer science focused in areas relevant to high performance computing. The results of this research are brought to the broader scientific communities through the Scientific Discovery through Advanced Computing (SciDAC) program. SciDAC facilitates the transfer basic research efforts into computational science applications through direct partnerships between ASCR-supported applied mathematicians and computer scientists, and domain experts in a specific discipline supported by other Office of Science (SC) programs, such as climate, astrophysics, materials, or fusion. These partnerships have been spectacularly successful with documented improvements in code performance in excess of 10,000 percent.

Researchers have a need to communicate with each other, exchange large data sets, and run complex calculations and experiments in remote scientific user facilities. To facilitate the best collaborations for science, ASCR has had a leading role in driving development of the networks connecting these researchers. Today, the invisible glue that binds all the networks in the world together and effortlessly passes billions of searches and trillions of bits has roots in ASCR research. ASCR researchers helped to establish critical protocols such as TCP/IP on which the current Internet is based. ASCR advanced networking research also makes international collaborations such as the Large Hadron Collider and ITER possible. The Internet has removed barriers between people and ASCR's advanced scientific networks have removed barriers between scientists and research facilities.

Looking forward, ASCR will continue to be guided by science needs as it develops computers and networks at the leading edge of technology. The ASCR approach of integrating research results across disciplines and with forefront facilities has been the key to its history of success in computational science. With this integrated approach ASCR will continue to deliver scientific insight to address national problems in energy and the environment.

Subprograms

To accomplish its mission and address the challenges described above, the ASCR program is organized into two subprograms—Mathematical, Computational, and Computer Sciences Research and High Performance Computing and Network Facilities.

- The *Mathematical, Computational, and Computer Sciences Research* subprogram develops mathematical descriptions, models, methods, and algorithms to describe and understand complex systems, often involving processes that span a wide range of time and/or length scales. The subprogram also develops the software to make effective use of advanced networks and computers, many of which contain thousands of multi-core processors with complicated interconnections, and to transform enormous data sets from experiments and simulations into scientific insight.
- The *High Performance Computing and Network Facilities* subprogram delivers forefront computational and networking capabilities and contributes to the development of next-generation capabilities through support of prototypes and testbeds.

Effective scientific utilization of high-end capability computing requires dynamic partnerships among application scientists, applied mathematics, computer scientists, and facility support staff. Therefore, close coordination both within and across ASCR subprograms and with partner organizations is key to the success of the ASCR program.

Benefits

Computer-based simulations enable us to model the behavior of complex systems that are beyond the reach of experiment or for which there is no theory. Because computer-based simulation is so important to research programs across SC and throughout the government, in addition to its core research program, ASCR invests in partnerships to advance use of high end computing in a wide array of disciplines important to DOE and operates the Leadership Computing Facilities as open user facilities with access determined by merit evaluation of proposals.

Many of the applications running on ASCR facilities have direct benefit to science and society at large. For example, SciDAC efforts include:

- Computational chemistry and simulation of nanomaterials is relevant to energy applications. These applications are funded in partnership with the Basic Energy Sciences program.
- The next generation Earth System Models will dramatically improve our ability to predict changes in global climate. This work is funded in partnership with the Biological and Environmental Research program. ASCR also provides the majority of the computing and networking resources for the U.S. contributions to the Intergovernmental Panel on Climate Change.
- Simulations of fusion reactors help to develop fusion as a viable energy source. This work is jointly funded with the Fusion Energy Sciences program.
- Computer modeling of nuclear structure has relevance for science, nuclear energy, and nuclear weapons. These applications are through partnerships with both the Nuclear Physics program and the National Nuclear Security Administration.
- Understanding the origin and fate of the universe is the goal of partnerships with the High Energy Physics program that include analyzing massive amounts of data from experiments, such as the Large Hadron Collider, and conducting simulations, such as three dimensional simulations of supernovae events, which are only possible with leadership computing resources.

- Simulations of biological systems relevant for bioenergy applications and subsurface science research characterizes and predicts changes in DOE's environmental management sites. This work also has implications for DOE's efforts in subsurface carbon sequestration. These applications are partnerships with the Biological and Environmental Research Program.

Establishing SC Leadership Computing Facilities has required partnerships with hardware vendors to develop the most appropriate architectures for scientific discovery and the software necessary to effectively use these powerful systems. These partnerships benefit many sectors of the economy from high-tech industry and academic research to software development and engineering. Finally, ASCR's support of researchers and students (the next generation of researchers) is a benefit to the national research and development workforce.

Program Planning and Management

The ASCR program has developed a system of planning and priority setting that benefits strongly from groups of outside experts. ASCR has also instituted a number of peer review and oversight processes designed to assess the quality, relevance, and performance of the ASCR portfolio on a regular basis. One way in which ASCR ensures the integrity and effectiveness of the peer review processes is through the Advanced Scientific Computing Advisory Committee (ASCAC), which organizes regular Committees of Visitors to review ASCR research management, the impact of the ASCR scientific user facilities, and progress toward the long-term goals of the program. In addition, ASCAC identifies scientific challenges and opportunities, including specific bottlenecks to progress in areas such as climate change or computational biology, and comments on the overall balance of the ASCR portfolio.

In addition to ASCAC, critical tools for managing the ASCR scientific user facilities include annual operational reviews and requirements workshops. For example, ESnet conducts two network requirements workshops per year with individual SC program offices. The purpose of each workshop is to accurately characterize the near-term, medium-term, and long-term network requirements of the science conducted by each program office. Since two workshops are conducted per year, ASCR refreshes the network requirements information for each of the six program offices every three years.

Community-driven workshops are another critical means by which dialogues are facilitated and new research opportunities are identified. For example, there were a series of workshops in 2009 to identify key science opportunities in the disciplines important to DOE—nuclear energy, materials and chemistry, high energy and nuclear physics, climate change, biology, and cross-cutting areas—and the potential role of extreme scale computing in realizing those opportunities.

Another important planning and coordination mechanism for ASCR is the National Science and Technology Council's (NSTC) subcommittee on Networking and Information Technology Research and Development (NITRD). ASCR is a major participant in the NITRD program[a], which coordinates Federal research investments by the 11 member agencies in advanced information technologies such as computing, networking, and software through interagency working groups and coordinating groups. ASCR is a major participant and/or chair of the High End Computing Research and Development, Large Scale Networking, and High End Computing Infrastructure and Applications groups.

In October 2008, the National Research Council published a study titled "The Potential Impact of High-End Capability Computing (HECC) on Four Illustrative Fields of Science and Engineering"[b] that identifies and categorizes important scientific questions and technology problems for which an

[a] Information on the NITRD program can be found at http://www.nitrd.gov.
[b] The "The Potential Impact of High-End Capability Computing (HECC) on Four Illustrative Fields of Science and Engineering" can be found at http://www.nap.edu/catalog.php?record_id=12451

extraordinary advancement in our understanding is difficult or impossible without leading edge scientific simulation capabilities. In all four fields studied—atmospheric sciences, astrophysics, separations chemistry, and evolutionary biology—the committee found continuing demand for more powerful high end computing and for large scale data management. The report outlined the major scientific challenges in the four fields and estimated the associated challenges in mathematics, computer science, and computing infrastructure. The conclusions of the report underscore the importance of balancing investments in high potential application areas, the high-end computing resources required by multiple fields, and the longer-term mathematics and computer science research that underpins continued progress. The report also emphasizes the added importance of linking these efforts: “In many cases HECC capabilities must continue to be advanced to maximize the value of data already collected…The committee foresees a growing need for computational scientists and engineers who can work with mathematicians and computer scientists to develop next-generation code.”

Basic and Applied R&D Coordination

A cornerstone of the ASCR program is coordination across disciplines and programs. Partnerships within SC are mature and continue to advance the use of high performance computing and scientific networks for science. In addition, ASCR continues to have a strong partnership with the National Nuclear Security Administration in areas of mutual interest including best practices for management of high performance computing facilities. Through NITRD, ASCR coordinates with similar programs across the federal government and directly partners with the Department of Defense on developing High Productivity Computing Systems and software and with the National Science Foundation on the Open Science Grid.

In discussions with the technology development programs throughout DOE, a key area of mutual interest continues to be in applied mathematics for the optimization of complex systems, control theory, and risk assessment. In March 2009, a workshop was organized, in partnership with the Office of Electricity Delivery and Energy Reliability, which focused on the challenges of grid modernization efforts. This workshop is part of a series of workshops on basic research needs in applied R&D areas. Other workshops have covered advanced nuclear energy systems (with the Office of Nuclear Energy), subsurface science (with the Offices of Environmental Management, and Fossil Energy), cyber security (with the Office of Electricity Delivery and Energy Reliability), and alternative and renewable energy (with the Office of Energy Efficiency and Renewable Energy). These workshops facilitate a dialogue between the ASCR research community and a specific applied R&D community and identify opportunities for new research. This research becomes part of the ASCR program through investigator driven research proposals and is coordinated with the applied efforts through program manager interactions and joint principal investigator meetings.

Budget Overview

The FY 2011 ASCR budget request capitalizes on the continued gains in computer hardware and in computational science and positions DOE to address scientific challenges through modeling and simulation in the next decade. Since the challenges ahead will require major advances in hardware, software, methods, and tools, the request balances investments in high performance computing facilities, advanced networks, and research and evaluation prototypes with investments in applied mathematics, computer science, next generation networks for science, and computational partnerships. This balance should allow for continued progress in a wide array of fields important to DOE’s missions in FY 2011 and for years to come.

The FY 2011 budget request continues support for the Leadership Computing Facility at Oak Ridge National Laboratory (OLCF)—a 2.33 petaflop, six-core Cray Baker system, openly available to the scientific community through the Innovative and Novel Computational Impact on Theory and Experiment (INCITE) program. In addition to INCITE projects, the OLCF will continue to provide access and assistance to tool and library developers and to researchers seeking to scale their application to this new realm of computing power. These activities are critical to harnessing the complexity of this architecture and meeting challenges associated with high performance computer systems with tens of thousands of multicore processors. Efforts at the OLCF are also expected to build experience and tools for the DARPA High Productivity Computing Systems award to Cray, supported in part through ASCR's Research and Evaluation Prototypes activity, and other anticipated architectures that will exhibit even greater complexity.

The FY 2011 budget request also continues support for the Leadership Computing Facility at Argonne National Laboratory (ALCF)—a 556 teraflop IBM Blue Gene/P system also openly available to the scientific community through INCITE. Like the OLCF, the ALCF will continue to provide access and assistance to tool and library developers and to researchers seeking to scale their applications. The FY 2011 budget request also includes site preparation and acquisition activities for a next generation machine of approximately10 petaflops. Development of this proposed machine is based on the joint ASCR-NNSA sponsored research project with IBM and the Argonne and Lawrence Livermore National Laboratories that was supported from FY 2006 to FY 2010 through the Research and Evaluations Prototypes activity.

The National Energy Research Scientific Computing Center (NERSC) facility at Lawrence Berkeley National Laboratory (LBNL) will operate at a capacity of nearly one petaflop in FY 2011 to meet ever growing demand from SC researchers. Focus will be on assisting applications to effectively utilize the potential of this facility and to move beyond NERSC to the leadership computing machines.

The FY 2011 budget request supports ESnet to continue to advance the next generation network capability that is critical to DOE applications and facilities. Building on the Recovery Act-supported Advanced Networking Initiative, ESnet will deliver 100–400 gigabit per second (Gbps) connections to SC laboratories in FY 2011, with a goal of achieving 1,000 Gbps connectivity in 2014. These increases in bandwidth are necessary to move massive amounts of data to and from the petascale computing facilities and from other research facilities such as the Large Hadron Collider and Spallation Neutron Source. The ESnet is also critical to effective utilization of the growing amounts of data in climate research, nuclear structure, genomics, and proteomics that advance DOE's energy and environment missions.

The FY 2011 budget continues the research efforts in Scientific Discovery through Advanced Computing (SciDAC) and the core research programs in Applied Mathematics and Computer Science that enable scientists to effectively utilize the capabilities of the Leadership Computing Facilities while beginning to lay the basic research foundation necessary to realize the potential from the more complex systems on the horizon. Core research in Applied Mathematics and Computer Science for FY 2011 will continue to focus on long-term research needs. In networking, the focus will continue to be on developing the advanced tools to harness the growing capabilities and requirements of the ESnet and the SC research community.

Significant Program Shifts

The demands of some critical science applications require us to look ahead to more advanced computing architectures. In FY 2010, ASCR launched a new computer science core research effort in advanced computing architectures. The FY 2011 budget enhances this effort with new projects in the Research and Evaluations Prototypes activity that replace completed projects. These projects will provide the ASCR research community with an opportunity to experiment with cutting-edge architectures and begin to develop tools and methods for harnessing their capabilities. Physical limits to miniaturization necessitate a period of innovation and collaboration for continued progress to be realized. By actively participating in the development of these next-generation machines, ASCR can ensure that the most appropriate architecture for science is developed while researchers better understand their inherent challenges and can begin to work on overcoming those challenges. This activity will prepare researchers to effectively utilize the next generation of scientific computers and will also reduce the risk of future major procurements.

In FY 2011, SciDAC will be expanded to include partnerships with DOE's applied technology offices such as the Office of Electricity Delivery and Energy Reliability and the Office of Nuclear Energy.

Annual Performance Targets and Results

Secretarial Priority: Innovation: Lead the world in science, technology, and engineering

GPRA Unit Program Goal: Advanced Scientific Computing Research Program Goal: Deliver forefront computational and networking capabilities—Deliver forefront computational and networking capabilities to scientists nationwide that enable them to extend the frontiers of science, answering critical questions that range from the function of living cells to the power of fusion energy.

Annual Performance Measure: Average annual percentage increase in the computational effectiveness (either by simulating the same problem in less time or simulating a larger problem in the same time) of a subset of application codes, tools and/or libraries.

FY 2006	T: Computational effectiveness is greater than 50%. A: Goal met
FY 2007	T: Achieved computational effectiveness is 100% or greater. A: Goal met
FY 2008	T: Achieved computational effectiveness is 100% or greater. A: Goal met
FY 2009	T: Achieved computational effectiveness is 100% or greater. A: Goal met
FY 2010-FY 2015	T: Achieved computational effectiveness is 100% or greater. A: TBD

Annual Performance Measure: Focus usage of the primary supercomputer at the National Energy Research Scientific Computing Center (NERSC) on capability computing.

FY 2006	T: Percentage of the computing time used that is accounted for by computations that require at least $^1/_8$ of the total resource is at least 40%. A: Goal met

FY 2007	T: Percentage of the computing time used that is accounted for by computations that require at least $^1/_8$ of the total resource is at least 40%. A: Goal met
FY 2008	T: Thirty percent (30%) of the computing time will be used by computations that require at least $^1/_8$ (2,040 processors) of the NERSC resource. A: Goal met
FY 2009	T: At least forty percent (40%) of the computing time will be used by computations that require at least $^1/_8$ (2,040 processors) of the NERSC resource. A: Goal met
FY 2010	T: At least 30% of the computing time will be used by computations that require at least $^1/_8$ (4,096 processors) of the NERSC resource. A: TBD
FY 2011	T: At least 30% of the computing time will be used by computations that require at least $^1/_8$ of the NERSC resource. A: TBD
FY 2012	T: At least 35% of the computing time will be used by computations that require at least $^1/_8$ of the NERSC resource. A: TBD
FY 2013-FY 2015	T: At least 40% of the computing time will be used by computations that require at least $^1/_8$ of the NERSC resource. A: TBD

Mathematical, Computational, and Computer Sciences Research

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Mathematical, Computational, and Computer Sciences Research			
Applied Mathematics	45,161	44,792	45,450
Computer Science	30,782	46,800	47,400
Computational Partnerships	59,698	53,293	53,297
Next Generation Networking for Science	14,732	14,321	14,321
SBIR/STTR	0	4,586	4,623
Total, Mathematical, Computational, and Computer Sciences Research	150,373	163,792	165,091

Description

The Mathematical, Computational, and Computer Sciences Research subprogram supports elements of the ASCR program aimed at effectively utilizing forefront computational and networking capabilities. Computational science is increasingly central to progress at the frontiers of science and to our most challenging feats of engineering. Accordingly, the subprogram must be positioned to address scientifically challenging questions, such as:

- What new mathematics are required to more accurately model systems such as the earth's climate and the behavior of living cells that involve processes taking place on vastly different time and/or length scales?
- Which computational architectures and platforms will deliver the most benefit for the science of today and the future?
- What innovations in computer science and algorithms are needed to increase the efficiency with which supercomputers solve problems?
- What operating systems, data management, analyses, representation model development, user interfaces, and other tools are required to make effective use of future-generation supercomputers?
- What tools are needed to make all scientific resources readily available to scientists, regardless of whether they are at a university, national laboratory, or industrial setting?

FY 2009 Accomplishments

- *ASCR Research wins R&D 100 Awards.* Winning a R&D 100 award, often dubbed the "Oscars of invention," provides a mark of excellence known to industry, government, and academia for one of the most innovative ideas of the year. In FY 2009, ASCR-supported research in mathematical libraries and software toolkits, compiler development, and operating systems garnered three of these coveted awards in the software category—PETSc, a suite of data structures and routines for the scalable (parallel) solution of partial differential equation; ROSE, a compiler infrastructure that radically changes the accessibility of compiler technologies and enables users to build their own tools and easily develop programs for today's fast changing hardware platform; and the Catamount

N-Way lightweight kernel, an operating system that leverages hardware capabilities of multicore processors to deliver significant improvements in data access performance for today's parallel computing applications. (The Catamount team is supported by ASCR and builds on work previously supported by the NNSA Advanced Simulation and Computing program.)

- *41 DOE-Affiliated Researchers Named SIAM Fellows***.** The Society for Industrial and Applied Mathematics (SIAM) announced its first class of fellows on May 1, 2009, and the group included 14 current and retired mathematicians from DOE national laboratories, as well as 27 other mathematicians supported by ASCR. This represents about 20 percent of the 200 fellows selected by the society from its international membership of more than 12,000 mathematicians.
- *New General Model for Detecting MPI Deadlocks Developed.* The Message Passing Interface (MPI) standard enables massively parallel processing by directing communications between processors. However, several usage patterns can lead to deadlocks and cause programs to fail. Deadlocks are particularly troublesome because they occur inconsistently and sporadically. They are also very hard to find and fix—especially in long and complicated programs. However, ASCR researchers have developed the first general deadlock model using a graph-based approach. This model enables visualization of MPI deadlocks and motivates the design of a new deadlock detection mechanism. Overall, the results demonstrate that the mechanism improves performance by as much as two orders of magnitude while providing precise characterization of deadlocks.
- *Scaling of Multimillion-Atom Biological Molecular Dynamics Simulation on a Petascale Supercomputer.* ASCR researchers published a strategy enabling molecular dynamics simulations of lignocellulosic biomass to scale to tens of thousands of processors at the OLCF. The strategy enabled the researchers to scale efficiently to the entire machine (140,000 processors). This work will have a significant impact on a wide array of molecular dynamics simulations. Among other applications, the strategy will be of particular importance in bioenergy research.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
Applied Mathematics	**45,161**	**44,792**	**45,450**

The Applied Mathematics activity supports the research, development, and application of applied mathematical models, methods and algorithms to understand complex physical, chemical, biological, and engineered systems related to DOE's mission. The research falls into eight general categories, the first five of which have been supported for a number of years while the rest began in FY 2009

- Numerical methods research for equations related to problems such as wave propagation, electrodynamics, fluid flow, elasticity, and other natural or physical processes.
- Advanced linear algebra research for fast and efficient numerical solutions of linear algebraic equations that often arise when simulating physical processes. Because a large fraction of the time in many simulations is spent doing this type of computation, advances here have enormous leverage across science.
- Computational meshing research for developing ways in which space can be broken up into regions—often geometrically complex—for the purposes of simulation.

	(dollars in thousands)	
FY 2009	FY 2010	FY 2011

- Optimization research for mathematical methods for minimizing energy or cost, finding the most efficient solutions to engineering problems, or discovering physical properties and biological configurations. This includes optimization, control, and risk assessment in complex systems with relevance for DOE missions in energy, national security, and environment.
- Multiscale mathematics and multiphysics computations for connecting the very large with the very small, the very long with the very short, and multiple physical models in a single simulation.
- Joint Applied Mathematics-Computer Science Institutes for the development of efficient new mathematical models, algorithms, libraries, and tools for next generation computers.
- Mathematics for the analysis of extremely large datasets for identifying key features, determining relationships between the key features, and extracting scientific insights.
- Mathematics of cyber security from a basic research perspective for addressing the understanding and discovery of anomalies in existing network data, modeling of large-scale networks, and understanding dynamics and emergent behavior on networks. This leverages on-going efforts in the mathematics of optimization and risk assessment in complex systems.

These mathematical models, methods, and algorithms are the fundamental building blocks for describing physical and biological systems computationally. Applied Mathematics research underpins all of DOE's modeling and simulation efforts.

In FY 2011, this activity will continue to develop new and improved applied mathematical models, methods, and algorithms to understand complex systems—including the complex computing systems on which they will run. In addition, the Computational Science Graduate Fellowship program, aimed at attracting the best graduate students in the scientific disciplines and educating them as the next generation of computational scientists, is continued at $6,000,000, and the Applied Mathematics and High Performance Computer Science graduate fellowship program is continued at $2,000,000.

Computer Science	**30,782**	**46,800**	**47,400**

The Computer Science activity supports research to utilize computing at extreme scales and to understand extreme scale data from both simulations and experiments. The research falls into five general categories, the first four of which have been supported for a number of years and the last began in FY 2009.

- Operating and file systems for extreme scale computers with many thousands of multi-core processors with complicated interconnection networks.
- Performance and productivity tools for extreme scale systems that enable users to diagnose and monitor the performance of software and scientific application codes to enable users to improve performance and get scientific results faster.
- Programming models that enable today's computations and discover new models that scale to hundreds of thousands of processors to simplify application code development for petascale computing.
- Data management and visualization to transform extreme scale data into scientific insight through investments in visualization tools that scale to multi-petabyte datasets and innovative approaches to indexing and querying data.

	(dollars in thousands)	
FY 2009	FY 2010	FY 2011

- Joint Applied Mathematics-Computer Science Institutes for the development of efficient new mathematical models, algorithms, libraries, and tools for next generation computers. Leading edge developers to directly address the new challenges from the next generation of computers and transfer this insight to key DOE application developers.

The Computer Science activity addresses two fundamental challenges. The first challenge is enabling science applications to harness computer systems with increasing scale and increasing complexity due to technology advances such as multicore chips. This challenge will require more dynamic behavior of system software (operating systems, file systems, compilers, performance tools) than historically developed. Substantial innovation is needed to provide essential system software functionality in a timeframe consistent with the anticipated availability of hardware. The second challenge is enabling scientists to effectively manage, analyze, and visualize the petabytes of data that result from extreme scale simulations and experimental facilities. Substantial innovation in computer science and applied mathematics is needed to provide essential system and application functionality in a timeframe consistent with the anticipated availability of hardware.

In FY 2011, the Computer Science activity will continue to focus on the challenges of emerging extreme scale architectures containing tens of thousands to millions of multicore and/or hybrid processors.

	FY 2009	FY 2010	FY 2011
Computational Partnerships	**59,698**	**53,293**	**53,297**

The Computational Partnerships activity supports the Scientific Discovery through Advanced Computing (SciDAC) program to use results from applied mathematics and computer science research on scientific applications sponsored by other SC programs. These partnerships enable improved performance on high-end computing systems for scientists to conduct complex scientific and engineering computations at a level of detail that begins to resemble real-world conditions. The activities fall into four general categories:

- Nine multi-institutional *Centers for Enabling Technologies* represent almost half of the ASCR SciDAC activity. They are a focal point for bringing together a critical mass of leading experts from multiple disciplines to focus on key problems in a particular area such as performance, data management, optimization, or visualization. These SciDAC Centers address needs for new methods, algorithms and libraries; new methodologies for achieving portability and interoperability of complex scientific software packages; software tools and support for application performance; and more effective tools for feature identification, data management, and visualization.
- Four multi-institutional SciDAC Institutes are university-led centers of excellence which complement the efforts of the SciDAC Centers but with a role in the education and training of the next generation of computational scientists. These institutes reach out to a broader community of scientists to advance scientific discovery through advanced computation, collaboration, and training of graduate students and postdoctoral fellows.
- 35 multi-institutional *Science Applications Partnerships* are partnerships with other SC programs to dramatically improve the ability of their researchers to effectively utilize petascale computing to advance science. These partnerships support collaborative research between applied mathematicians and computer scientists (supported by ASCR) with domain scientists (supported by the other

programs) to refine and apply computational techniques and tools that address the specific problems of a particular research effort, such as modeling the reactive transport of contaminants through groundwater or developing an Earth System model that fully simulates the coupling between the physical, chemical, and biogeochemical processes in the global climate.

- With more than 80 participating institutions and hundreds of researchers developing tools, techniques, and software that push the state-of-the-art in high performance computing, the *SciDAC Outreach Center* ensures that SciDAC teams share information across projects and leverage taxpayer investment with other researchers. This small virtual organization, linked to user support at the ASCR facilities and organized by LBNL, provides a single resource to facilitate and accelerate the transfer of tools, techniques, and methods to the broader research community. The SciDAC Outreach Center is also a resource for INCITE applicants who need assistance in readying their application for leadership facilities.

In FY 2010, the Computational Partnerships activity began to support a small number of new interdisciplinary teams focused on transforming critical DOE applications for extreme scale computing. These competitively selected teams will evaluate the impact of directions in computer hardware on application capability, form a critical interface to existing SciDAC Centers and Institutes on the tool and library implications of these developments, and develop the understanding needed to enable these applications to execute effectively on future computer architectures.

In FY 2011, completion of several of the SciDAC projects initiated in FY 2006 will enable an expansion of these critical efforts. ASCR will also initiate new SciDAC partnerships with the Office of Electricity Delivery and Energy Reliability and/or the Office of Nuclear Energy.

	FY 2009	FY 2010	FY 2011
Next Generation Networking Research for Science	**14,732**	**14,321**	**14,321**

The Next Generation Networking Research for Science activity builds on results from Computer Science and Applied Mathematics to develop integrated software tools and advanced network services to enable large-scale scientific collaboration and to utilize the new capabilities of ESnet to advance DOE missions. The research falls into two general categories:

- Distributed systems software including scalable and secure tools and services to facilitate large-scale national and international scientific collaboration and high-performance software stacks to enable the discovery, management, and distribution of extremely large data sets generated by simulations or by science experiments such the Large Hadron Collider, the Intergovernmental Panel on Climate Change, and ITER.
- Advanced network technologies including dynamic optical network services, scalable cyber security technologies, and multi-domain, multi-architecture performance protocols to seamlessly interconnect and provide access to distributed computing resources and science facilities.

In FY 2011, research will continue to focus on developing the software, middleware and hardware that delivers 99.999% reliability up to and beyond one petabyte per second.

	FY 2009	FY 2010	FY 2011
Small Business Innovative Research (SBIR)/ Small Business Technology Transfer (STTR)	**0**	**4,586**	**4,623**

In FY 2009, $3,612,000 and $432,000 were transferred to the SBIR and STTR programs respectively. The FY 2010 and FY 2011 amounts shown are the estimated requirements for continuation of the congressionally mandated SBIR and STTR programs.

	FY 2009	FY 2010	FY 2011
Total, Mathematical, Computational, and Computer Sciences Research	**150,373**	**163,792**	**165,091**

(dollars in thousands)

Explanation of Funding Changes

	FY 2011 vs. FY 2010 ($000)
Applied Mathematics	
This increase will support the continued development of new and improved applied mathematical models, methods, and algorithms to understand complex systems.	+658
Computer Science	
This increase will support continued focus on the challenges of emerging extreme scale architectures containing tens of thousands to millions of multicore and/or hybrid processors.	+600
Computational Partnerships	
The increase, in addition to the completion of several awards initiated in FY 2006, will support additional efforts focused on getting critical applications ready to utilize extreme scale computing resources and new partnerships with DOE applied programs.	+4
SBIR/STTR	
SBIR/STTR increases as research funding is increased.	+37
Total Funding Change, Mathematical, Computational, and Computer Sciences Research	**+1,299**

High Performance Computing and Network Facilities

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
High Performance Computing and Network Facilities			
High Performance Production Computing	53,497	55,000	56,000
Leadership Computing Facilities	116,222	123,168	158,000
Research and Evaluation Prototypes	10,387	16,124	10,052
High Performance Network Facilities and Testbeds	28,293	29,722	30,000
SBIR/STTR	0	6,194	6,857
Total, High Performance Computing and Network Facilities	208,399	230,208	260,909

Description

The High Performance Computing and Network Facilities subprogram delivers forefront computational and networking capabilities to scientists nationwide. These include the High Performance Production Computing at the National Energy Research Scientific Computing Center (NERSC) facility at LBNL and Leadership Computing Facilities at Oak Ridge (OLCF) and Argonne (ALCF) National Laboratories. These computers, and the other SC research facilities, turn out many petabytes of data each year. Moving data to the researchers who need them requires advanced scientific networks and related technologies provided through High Performance Network Facilities and Testbeds. The subprogram also invests in long-term needs through the Research and Evaluation Prototypes activity.

Computing resources are allocated through competitive processes. Up to eighty percent of the processor time on the Leadership Computing Facilities is allocated through the Innovative and Novel Computational Impact on Theory and Experiment (INCITE) program, which is open to all researchers and results in awards to a small number of projects, each requiring a substantial amount of the available resources. The high performance production computing facilities at NERSC are predominately allocated to researchers supported by SC programs. In FY 2011, all of the ASCR scientific computing facilities will also allocate ten to thirty percent of computing resources through the ASCR Leadership Computing Challenge program. This program is open year-round to scientists from the research community in academia and industry for special situations of interest to DOE with an emphasis on high-risk, high-payoff simulations in areas directly related to the DOE's energy mission, for national emergencies, or for broadening the community of researchers capable of using leadership computing resources.

FY 2009 Accomplishments

- *Oak Ridge Supercomputers Provide Understanding of the Conditions that Led to Past Abrupt Climate Changes*. Scientists at the University of Wisconsin and the National Center for Atmospheric Research (NCAR) used the OLCF to simulate abrupt climate change and shed new light on an enigmatic period of natural global warming in Earth's relatively recent history. The work was featured in the July 17, 2009 issue of the journal *Science* and provides valuable new data about the causes and effects of global climate change. The scientists used nearly a million processor hours in 2008 to run one-third of their simulation, from 21,000 years ago—the most recent glacial maximum—to 14,000 years ago—the planet's most recent major period of natural global warming.

With 4 million INCITE processor hours allocated on the OLCF for 2009-2011, they will complete the simulation, capturing climate from 14,000 years ago to the present and projecting it 200 years into the future. This research is funded by Biological and Environmental Research and the National Science Foundation through its paleoclimate program and support of NCAR.

- *Argonne Supercomputer Provides Breakthrough Computation of Thermal-Hydraulics in Nuclear Reactors.* The first simulation of the full physical configuration of 217 wire-wrapped fuel rods was run on the ALCF and achieved 80% parallel efficiency. The calculation of the pressure distribution of coolant flow exceeded 2.90 million spectral elements and used approximately 1 billion grid points. Over this three-year INCITE project many ASCR research innovations were utilized to improve scaling of the code without losing physical details. Experiments indicate that low pin count results do not extrapolate to higher pin counts because of the edge channel effects. These full scale results are allowing researchers to study coolant flow in a variety of core subassembly designs in order to optimize reactor performance.
- *National Energy Research Scientific Computing (NERSC) Helps Discover Cosmic Transients***.** An innovative new sky survey, the Palomar Transient Factory, used the unique tools and services of NERSC to uncover more than 40 supernovae, or stellar explosions, during the commissioning phase and astronomers expect to be able to annually discover thousands more of these relatively rare and fleeting cosmic events. Such events occur about once a century in the Milky Way galaxy and are visible for only a few months.
- *Energy Sciences Network (ESnet) stimulates 100 Gbps technologies for DOE*. The ever growing demand for network bandwidth from large science collaborations, such as the Large Hadron Collider, requires ESnet to push toward next generation technologies to meet demand. However, the recession seemed to have stalled development of these technologies in early 2009. As a result, Secretary Chu announced in March that the Department of Energy would use Recovery Act funding to accelerate progress and deploy a prototype 100-gigabit per second data network. Across Europe and Asia, announcements of similar demonstrations quickly followed and industry began rolling out new offerings. ESnet is managing the Recovery Act-funded research project on advanced networking that is deploying a 100 Gbps test bed to develop the tools and techniques necessary to utilize this technology in the ESnet backbone beginning in FY 2010. Because of the strong connections between ESnet and this Recovery Act project, ESnet will be upgraded seamlessly to meet the growing, complex needs of DOE and remains on a path to deliver 1 terabit per second connectivity in 2014.

Detailed Justification

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011
High Performance Production Computing	**53,497**	**55,000**	**56,000**

This activity supports the NERSC facility located at LBNL. NERSC delivers high-end capacity computing services and supports the SC research community. Nearly 3,100 computational scientists in about 400 projects use NERSC to perform basic scientific research across a wide range of disciplines including astrophysics, chemistry, climate modeling, materials, high energy and nuclear physics, and biology. NERSC enables teams to prepare to use the ALCF and OLCF as well as to perform the calculations that are required by the missions of the SC programs. NERSC users are supported by SC

	FY 2009	FY 2010	FY 2011
(dollars in thousands)			

programs with 60% based in universities, 29% in national laboratories, 6% in other government laboratories, and 3% in industry.

The costs for NERSC fall into three general areas: lease payments for high performance computing hardware, operations (space, power, cooling, maintenance, tapes, etc.), and operating and support staff.

NERSC's large user base requires an extremely agile support staff. Careful planning of upgrades is critical to meeting increasing demand within a stable funding profile.

FY 2011 funding will support operation of the NERSC high-end capability systems (NERSC-5 and NERSC-6), lease payments, and user support. With the acquisition and operation of NERSC-6, the total capacity of NERSC in FY 2011 will be approximately one petaflop. The NERSC computational resources are integrated by a common high performance file storage system that enables users to easily migrate to any of the available resources. With approximately 60 petabytes of storage and an average transfer rate in the hundreds of megabytes per second, this system also allows users to easily move data into and out of the NERSC facility.

	FY 2009	FY 2010	FY 2011
Achieved Operating Hours	8,585	N/A	N/A
Planned Operating Hours	8,585	8,585	8,585
Optimal Hours	8,585	8,585	8,585
Percent of Optimal Hours	100%	100%	100%
Unscheduled Downtime	1%	1%	1%
Number of Users	3,100	3,100	3,100

Leadership Computing Facilities	**116,222**	**123,168**	**158,000**

The Leadership Computing Facilities activity enables open scientific applications to harness the potential of leadership computing to advance science. 2009 saw the realization of that vision, with the top system in the independent international "Top 500" ranking of supercomputers and a second Gordon Bell prize for a petascale science application that provided new insights into magnetic materials. This new era of petaflop science opens significant opportunities to dramatically advance research as simulations more realistically capture the behavior of, for example, materials and ITER scale fusion devices. The success of this effort is built on the gains made in research and evaluation prototypes, the SciDAC program, and research in applied mathematics and computer science.

The costs for both the ALCF and OLCF fall into three general areas: lease payments, operations (space, power, cooling, maintenance, tapes, etc.), and operating and support staff. In FY 2011, costs are driven by increases in lease payments at both facilities in accordance with the approved baselines.

▪ **Leadership Computing Facility at ORNL (OLCF)**	**87,680**	**81,168**	**96,000**

In FY 2009, with Recovery Act funds, the OLCF's Cray XT5 system was upgraded to 2.33 petaflops—making it the most powerful computer in the world. In addition, the facility also continues to operate a 263 teraflop Cray XT4 machine for INCITE projects, ASCR Leadership Computing Challenge projects, scaling tests, and tool and library developers. The facility staff is

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

continuing to focus on assisting users to fully utilize the OLCF resources. As a result, several applications, such as combustion studies in diesel jet flame stabilization, simulations of neutron transport in fast reactor cores, and groundwater flow in porous media, are running at petascale.

In FY 2011, the request supports an increase in lease payments for the XT5 and the acquisition of an experimental prototype with a hybrid architecture—a mix of standard processors and specialized processing engines (such as a Global Processing Unit [GPU], a field-programmable gate array [FPGA], or a vector processor) that offer greater efficiency and computing power but also introduce new system and application programming challenges. The OLCF activity will also support operation and INCITE allocation of the two Cray systems and will continue to provide support to INCITE projects, pioneer applications, and tool and library developers.

	FY 2009	FY 2010	FY 2011
Achieved Operating Hours	7,008	N/A	N/A
Planned Operating Hours	7,008	7,008	7,008
Optimal Hours	7,008	7,008	7,008
Percent of Optimal Hours	100%	100%	100%
Unscheduled Downtime	1%	1%	1%
Number of Users	496	550	625

	FY 2009	FY 2010	FY 2011
▪ **Leadership Computing Facility at ANL (ALCF)**	**28,542**	**42,000**	**62,000**

The ALCF provides a high performance IBM Blue Gene/P with low-electrical power requirements and a peak capability of 556 teraflops. This facility provides diversity in the DOE leadership resources and supports many applications, including molecular dynamics and materials. This system is better suited to these computing needs than the OLCF and NERSC. The ALCF staff operate and maintain the computing resources and provide support to INCITE projects, ASCR Leadership Computing Challenge projects, scaling tests, and tool and library developers.

In FY 2011, the request supports increases in the lease payments on the Blue Gene/P in accordance with the approved schedule. In addition, ALCF will support site preparations for acquisition of a next generation machine. This machine is expected to be approximately 10-20 petaflops, such as the system being developed through the joint research project with NNSA and IBM on the Blue Gene/Q. The ALCF activity will also support operation and INCITE allocation of the Blue Gene/P in FY 2011 and will continue to provide support to INCITE projects, pioneer applications, and tool and library developers.

	(dollars in thousands)		
	FY 2009	FY 2010	FY 2011

	FY 2009	FY 2010	FY 2011
Achieved Operating Hours	7,008	N/A	N/A
Planned Operating Hours	7,008	7,008	7,008
Optimal Hours	7,008	7,008	7,008
Percent of Optimal Hours	100%	100%	100%
Unscheduled Downtime	1%	1%	1%
Number of Users	100	200	300

	FY 2009	FY 2010	FY 2011
Research and Evaluation Prototypes	**10,387**	**16,124**	**10,052**

The Research and Evaluation Prototypes activity addresses the challenges of next generation computing systems. As computer chips approach critical physical limits, we begin an era of radical innovation. These systems will likely be significantly more complex than current computing systems. As a result, many of the tools and techniques developed over the past decade will no longer be effective. By actively participating in the development of these next-generation machines, ASCR can ensure that the most appropriate architectures for science are developed while researchers will better understand their inherent challenges and can begin to work on overcoming those challenges. The Research and Evaluation Prototype activity will prepare researchers to effectively utilize the next generation of scientific computers and will also reduce the risk of future major procurements.

In FY 2011, the Research and Evaluation Prototypes activity will complete SC's partnership with the NNSA and the Defense Advanced Research Projects Agency (DARPA) program for High Productivity Computing Systems. ASCR will continue to work cooperatively with the NNSA on new, smaller scale prototype projects to explore architectures on the path toward exascale computing (capable of an exaflop, or 10^{18} floating point operations per second). These prototype projects will be tightly coupled with research in advanced computer architectures supported by the Computer Science activity.

	FY 2009	FY 2010	FY 2011
High Performance Network Facilities and Testbeds	**28,293**	**29,722**	**30,000**

This activity supports operation and upgrades for the Energy Science network (ESnet), which provides a high bandwidth network connecting DOE researchers with large-scale scientific user facilities and other scientific instruments. Each year the amount of data generated by these facilities roughly doubles. To meet demand, ESnet has partnered with Internet2—the leading provider of university networks—to push the state-of-the-art and deliver next generation optical network technologies that greatly expand capacity in the core science networks. Continued progress in high performance networks builds on the tools and knowledge developed by the Next Generation Networks for Science research activity and by innovations developed in partnership with Internet2.

The costs for ESnet are dominated by operations which includes refreshing hardware, such as switches and routers, on an accelerated schedule to ensure the 99.999% reliability that is required for large scale scientific data transmission.

In FY 2009, a Recovery Act supported research effort implemented a national testbed of next generation optical technologies that allow networks, such as ESnet, to gain a ten-fold increase in

		(dollars in thousands)	
	FY 2009	FY 2010	FY 2011

bandwidth on existing fiber. The testbed allows ASCR to develop and harden the tools necessary to ensure data integrity and network reliability with this new technology. In FY 2011, ASCR will begin to deploy this next generation technology to enable 100 Gbps per wavelength. As a result of research supported by the Recovery Act, ESnet is on a path to achieving 1,000 Gbps connectivity.

	FY 2009	FY 2010	FY 2011
Achieved Operating Hours	8,760	N/A	N/A
Planned Operating Hours	8,760	8,760	8,760
Optimal Hours	8,760	8,760	8,760
Percent of Optimal Hours	100%	100%	100%
Unscheduled Downtime	0.01%	0.01%	0.01%
Number of Users[a]	N/A	N/A	N/A

	FY 2009	FY 2010	FY 2011
Small Business Innovative Research (SBIR)/ Small Business Technology Transfer (STTR)	**0**	**6,194**	**6,857**

In FY 2009, $5,360,000 and $644,000 were transferred to the SBIR and STTR programs respectively. The FY 2010 and FY 2011 amounts shown are the estimated requirements for continuation of the congressionally mandated SBIR and STTR programs.

	FY 2009	FY 2010	FY 2011
Total, High Performance Computing and Network Facilities	**208,399**	**230,208**	**260,909**

Explanation of Funding Changes

	FY 2010 vs. FY 2009 ($000)
High Performance Production Computing	
The increase will support operation of the NERSC high-end capability systems (NERSC-5 and NERSC-6), lease payments, and user support.	+1,000
Leadership Computing Facilities (LCFs)	
The increase covers increases in lease payments at both facilities in accordance with approved schedule. The OLCF will acquire a prototype machine with a hybrid architecture. At the ALCF, the increase supports site preparation for acquisition of a next generation machine.	+34,832

[a] The ESnet is a high performance scientific network that connects DOE facilities to researches around the world and it is therefore not possible to estimate users.

	FY 2010 vs. FY 2009 ($000)
Research and Evaluation Prototypes	
The decrease is due to final payment for the DARPA High Productivity Computing Systems project. Support is increased for new, smaller scale prototype projects to explore architecture features on the path toward exascale computing.	-6,072
High Performance Network Facilities and Testbeds	
The increase will enable ESnet to begin to deliver 100 Gbps connections in FY 2011. The increase in bandwidth is critical to meeting the growing requirements for DOE applications and facilities.	+278
SBIR/STTR	
Increase in SBIR/STTR due to increase in operating expenses.	+663
Total Funding Change, High Performance Computing and Network Facilities	**+30,701**

Supporting Information

Operating Expenses, Capital Equipment, and Construction Summary

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
Operating Expenses	348,595	385,000	410,000
Capital Equipment	10,177	9,000	16,000
Total, Advanced Scientific Computing Research	358,772	394,000	426,000

Funding Summary

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
Research	160,760	186,110	182,000
Scientific User Facility Operations	198,012	207,890	244,000
Total, Advanced Scientific Computing Research	358,772	394,000	426,000

Scientific User Facility Operations

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
NERSC	53,497	55,000	56,000
OLCF	87,680	81,168	96,000
ALCF	28,542	42,000	62,000
ESnet	28,293	29,722	30,000
Total, Scientific User Facility Operations	198,012	207,890	244,000

Facilities Users and Hours

	FY 2009	FY 2010	FY 2011
NERSC			
Achieved Operating Hours	8,585	N/A	N/A
Planned Operating Hours	8,585	8,585	8,585
Optimal Hours	8,585	8,585	8,585
Percent of Optimal Hours	100%	100%	100%
Unscheduled Downtime	1%	1%	1%
Number of Users	3,100	3,100	3,100

	FY 2009	FY 2010	FY 2011
ESnet			
Achieved Operating Hours	8,760	N/A	N/A
Planned Operating Hours	8,760	8,760	8,760
Optimal Hours	8,760	8,760	8,760
Percent of Optimal Hours	100%	100%	100%
Unscheduled Downtime	0.01%	0.01%	0.01%
Number of Users	N/A	N/A	N/A
OLCF			
Achieved Operating Hours	7,008	N/A	N/A
Planned Operating Hours	7,008	7,008	7,008
Optimal Hours	7,008	7,008	7,008
Percent of Optimal Hours	100%	100%	100%
Unscheduled Downtime	1%	1%	1%
Number of Users	496	550	625
ALCF			
Achieved Operating Hours	7,008	N/A	N/A
Planned Operating Hours	7,008	7,008	7,008
Optimal Hours	7,008	7,008	7,008
Percent of Optimal Hours	100%	100%	100%
Unscheduled Downtime	1%	1%	1%
Number of Users	100	200	300
Total			
Achieved Operating Hours	31,361	N/A	N/A
Planned Operating Hours	31,361	31,361	31,361
Optimal Hours	31,361	31,361	31,361
Percent of Optimal Hours	100%	100%	100%
Unscheduled Downtime	1%	1%	1%
Number of Users	3,696	3,850	4,025

Scientific Employment

	FY 2009 Estimated	FY 2010 Estimated	FY 2011 Estimated
# University Grants	205	210	210
Average Size	$194,000	$224,000	$232,000
# Laboratory Projects	175	180	185
# Graduate Students (FTEs)	533	563	582
# Permanent Ph.D.s (FTEs)	735	766	791
# Other (FTEs)	248	246	281