DIRECTORATE FOR COMPUTER AND INFORMATION SCIENCE AND ENGINEERING (CISE) $954,410,000 +$32,680,000 / 3.5%

CISE Funding

(Dollars in Millions)

	FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	Change Over FY 2015 Estimate Amount	Change Over FY 2015 Estimate Percent
Advanced Cyberinfrastructure (ACI)	$211.93	$218.80	$227.29	$8.49	3.9%
Computing and Communication Foundations (CCF)	184.88	191.33	198.59	7.26	3.8%
Computer and Network Systems (CNS)	220.02	227.66	236.32	8.66	3.8%
Information and Intelligent Systems (IIS)	184.87	191.65	198.94	7.29	3.8%
Information Technology Research (ITR)	90.91	92.29	93.27	0.98	1.1%
Total, CISE	**$892.60**	**$921.73**	**$954.41**	**$32.68**	**3.5%**

Totals may not add due to rounding.

About CISE

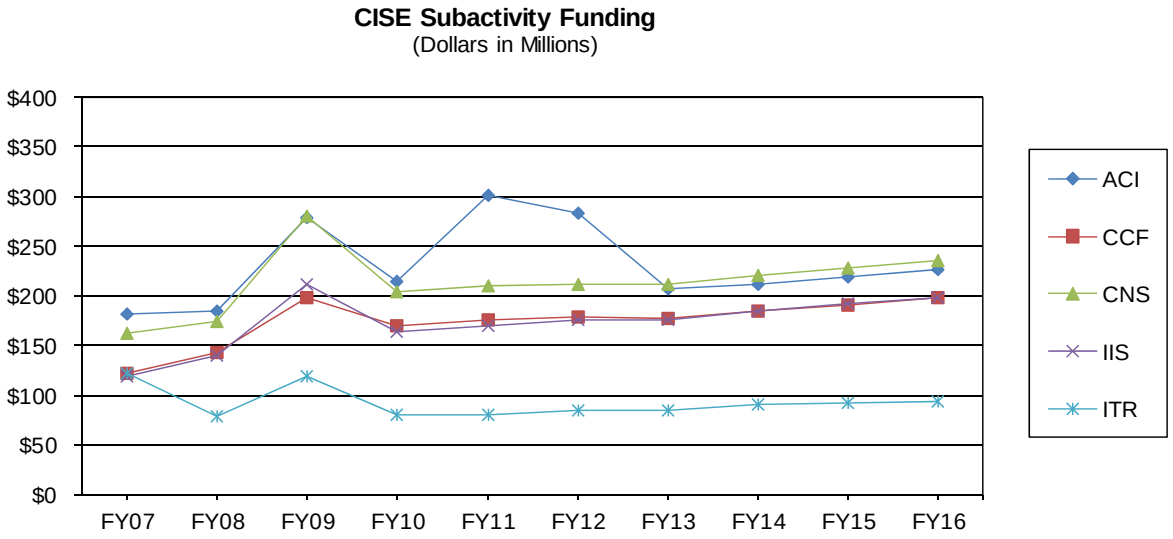
CISE's mission is to promote the progress of computer and information science and engineering research and education, and advance the development and use of cyberinfrastructure; to promote understanding of the principles and uses of advanced computer, communications, and information systems in service to society; and to contribute to universal, transparent, and affordable participation in a knowledge-based society. CISE supports ambitious long-term research and research infrastructure projects within and across the many sub-fields of computing, as well as cyberinfrastructure for all areas of science and engineering; contributes to the education and training of computing professionals; and, more broadly, informs the preparation of a U.S. workforce with computing and computational competencies essential to success in an increasingly competitive global market.

CISE's FY 2016 Budget Request is shaped by the following NSF-wide priorities: Cyber-enabled Materials, Manufacturing, and Smart Systems (CEMMSS), which includes Advanced Manufacturing, Cyber-Physical Systems (CPS), Designing Materials to Revolutionize and Engineer our Future (DMREF), and the National Robotics Initiative (NRI); Clean Energy Technology, which includes Innovations at the Nexus of Food, Energy, and Water Systems (INFEWS); Cyberinfrastructure Framework for 21st Century Science, Engineering, and Education (CIF21); Secure and Trustworthy Cyberspace (SaTC); Risk and Resilience; Understanding the Brain (UtB); NSF Inclusion across the Nation of Communities of Learners that have been Underrepresented for Diversity in Engineering and Science (NSF INCLUDES); NSF Innovation Corps (I-Corps™); and NSF Research Traineeship (NRT). Progress in foundational research and education in these areas is vital to address key national challenges, spur innovation, increase productivity, secure critical infrastructure, improve data analysis and sharing, and develop the next generation of computing and computational scientists.

CISE continues to provide leadership for the multi-agency Subcommittee on Networking and Information Technology Research and Development (NITRD), which is co-chaired by the CISE Assistant Director. All research, education, and research infrastructure projects supported by CISE enrich the agency's NITRD portfolio. As noted by the President's Council of Advisors on Science and Technology (PCAST) in its *Report to the President and Congress - Designing a Digital Future: Federally Funded Research*

and Development in Networking and Information Technology (January 2013),[1] advances in Networking and Information Technology (NIT) are key drivers of U.S. economic competitiveness. Essentially all practical applications of Information Technology are based on ideas and concepts that emerged from investments in basic computing research, driving discovery and innovation in many other areas, e.g., frontiers of scientific research, advanced manufacturing, education and workforce development, health and wellness technologies, sustainability and energy science, transportation, national and homeland security research, and public and private organizational effectiveness and efficiency. These fundamental ideas and concepts have enabled innovative products and applications that now permeate all areas of modern life, positioning NSF and CISE as central and essential actors in improving the Nation's economic outlook and advancing a highly trained, technologically-astute workforce.

CISE provides about 89 percent of the federal funding for basic research at U.S. academic institutions in computer science.



FY 2009 funding reflects both the FY 2009 omnibus appropriation and funding provided through the American Recovery and Reinvestment Act of 2009 (P.L. 111-5).

FY 2016 Summary by Division

- ACI's FY 2016 Budget Request will provide increased data and computational capacity that will allow more researchers and research communities to participate in multi-disciplinary priority areas, such as UtB and INFEWS. ACI will continue to invest in existing programs in computational science, software, data, networking, and cybersecurity. The division also will provide leadership in the NSF-wide CIF21 investment through funding for programs such as Data Infrastructure Building Blocks (DIBBs), Software Infrastructure for Sustained Innovation (SI^2), EarthCube, and Computational- and Data-Enabled Science & Engineering (CDS&E). These investments will include support for Data Science Pilots in partnership with other NSF directorates. ACI will continue to support other cross-disciplinary activities, including transitioning discoveries into practice in the SaTC program, and participating in Risk and Resilience investments. ACI remains responsible for providing national resources and instruments to facilitate collaborations and greater data sharing across research communities. ACI-supported infrastructure will be used to address some of the most difficult and complex research problems in all areas of science and engineering. For example,

[1] www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-nitrd2013.pdf

researchers can take advantage of two significant ACI-supported computational resources that became available in FY 2013: Blue Waters and Stampede.

- CCF's FY 2016 Budget Request is focused on maintaining support for its core programs as well as NSF-wide investments. CCF will continue to support CIF21 through investments in Big Data foundational research, including algorithms and software tools for managing massive amounts of heterogeneous, complex data; new functional capabilities in support of highly parallel computing; and multi-core and multi-machine data management systems. CCF will invest in INFEWS, with a focus on innovative optimization techniques, algorithms, and software development, as part of its support for Clean Energy Technology. CCF will support UtB by investing in the foundational capabilities necessary to integrate computational models across multiple scales. CCF will continue to invest in eXploiting Parallelism and Scalability (XPS) as part of its core programs. CCF will maintain its investment in Algorithms in the Field (AitF), promoting closer collaboration between theoretical computer science researchers and systems and domain experts. CCF will continue to support foundational research in SaTC, including new theories, models, methods, architectures, and tools that aim to achieve security-aware computing, self-healing hardware, and self-protecting software. As part of the National Nanotechnology Initiative (NNI), CCF will focus on foundational research and nanoscale devices and systems, and will invest in the National Nanotechnology Coordinated Infrastructure (NNCI), the successor to the National Nanotechnology Infrastructure Network (NNIN).

- CNS's FY 2016 Budget Request is focused on maintaining support for its core programs as well as NSF-wide investments. CNS will continue to lead the SaTC program in partnership with the Directorates for Education and Human Resources (EHR); Engineering (ENG); Mathematical and Physical Sciences (MPS); and Social, Behavioral, and Economic Sciences (SBE), as well as the other divisions in CISE. CNS will support CEMMSS through leadership of the CPS program in partnership with the Department of Homeland Security (DHS), Department of Transportation (DOT), National Aeronautics and Space Administration (NASA), National Institutes of Health (NIH), ENG, and other CISE divisions. Additionally, CNS will maintain its support for CIF21 through Big Data research on pervasive computing and large-scale data management systems. With EHR and the other CISE divisions, CNS will continue to support the STEM + Computing (STEM + C) Partnerships. CNS will support the development of multidisciplinary urban science, enabling effective integration of networked computing systems, physical devices, data sources, and infrastructure leading to smart cities. CNS will continue its support for mid-scale network infrastructure, including the development of NSFFutureCloud prototypes that provide programmable testbeds for experimenting with novel cloud architectures addressing emerging challenges such as high-confidence systems.

- IIS's FY 2016 Budget Request is focused on maintaining support for its core programs as well as NSF-wide investments. IIS will increase its investments in cognitive science and neuroscience in support of UtB, building on investments in computational neuroscience and foundational research programs to advance understanding of brain functions. IIS will participate in CEMMSS through leadership of NRI, in partnership with four federal agencies (Defense Advanced Research Projects Agency (DARPA), NASA, NIH, U.S. Department of Agriculture (USDA)), three other NSF directorates (ENG, EHR, and SBE), and other CISE divisions. NRI will accelerate the development and use of robots in the U.S. that work beside or cooperatively with people. IIS will participate in CIF21, and will provide leadership in Big Data research activities. This will include funding for new approaches to data mining, machine learning, knowledge extraction, visualization, predictive modeling, and automated discovery. IIS will invest in INFEWS, supporting novel approaches for large-scale data analysis and management. IIS also will continue to lead the joint NSF–NIH Smart and Connected Health (SCH) program, partnering with ENG, SBE, and other CISE divisions. Additionally, with EHR and ENG, IIS will continue to lead the Cyberlearning and Future Learning

Technologies (Cyberlearning) program, which aims to integrate advances in technology with advances in understanding how people learn, with a focus on online learning environments.

- ITR's FY 2016 Budget Request supports emerging high-priority areas of potentially transformative research. Through increased investments in I-Corps™, ITR will build on foundational research and guide the output of scientific discoveries in the development of technologies, products, and processes that benefit society. ITR will continue to invest in the center-scale Expeditions in Computing program. ITR will invest in multi-disciplinary research networks, aiming to build communities across emerging areas of research and education. ITR will increase its investments in multidisciplinary urban science, working with other CISE divisions and ENG and SBE to support effective integration of networked computing systems, physical devices, data sources, and infrastructure leading to smart cities. ITR will continue its investments in mid-scale prototypes for an NSFFutureCloud research infrastructure, extending virtualization beyond the network to large-scale, interconnected computing resources and enabling future cloud and distributed computing experimentation otherwise not possible. Through US Ignite, ITR will continue to integrate cities/regions and advance networking and systems research through experimentation and explorations at scale as well as through research in public-sector gigabit application development and deployment.

Major Investments

CISE Major Investments

(Dollars in Millions)

Area of Investment	FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	Change Over FY 2015 Estimate Amount	Change Over FY 2015 Estimate Percent
CAREER	$49.85	$45.50	$47.78	$2.28	5.0%
CEMMSS	85.00	89.00	94.11	5.11	5.7%
Advanced Manufacturing	*39.63*	*41.27*	*43.25*	*1.98*	*4.8%*
Clean Energy Technology	18.00	21.00	22.57	1.57	7.5%
CIF21	85.00	84.21	84.21	-	-
I-Corps™	8.15	11.00	11.65	0.65	5.9%
NSF INCLUDES	-	-	1.78	1.78	N/A
INFEWS	-	-	13.50	13.50	N/A
NRT[1]	1.40	13.38	9.69	-3.69	-27.6%
Risk and Resilience	4.00	6.50	8.00	1.50	23.1%
SaTC	71.18	70.00	70.50	0.50	0.7%
Understanding the Brain	11.58	16.50	28.58	12.08	73.2%
Urban Science	-	1.00	3.50	2.50	250.0%

Major investments may have funding overlap and thus should not be summed.

[1] Outyear commitments for Integrative Graduate Education and Research Traineeship (IGERT) are included in the NRT line and are $1.40 million in FY 2014 and $130,000 in FY 2015.

- CAREER: This program invests in the integration of research and education of early-career researchers and contributes to the development of future generations of computer and information scientists and engineers, as well as computational scientists across all areas of science and engineering.

- CEMMSS: CISE, in partnership with BIO, EHR, ENG, and MPS, aims to establish a scientific basis for engineered systems interdependent with the physical world and social systems, synthesize multi-disciplinary knowledge to model and simulate systems in their full complexity and dynamics, and develop a smart systems technology framework and multidisciplinary urban science. The CPS program, a component of CEMMSS, promises to accelerate advances in 21st-century smart engineered systems, in partnership with four other federal agencies (DHS, DOT, NASA and NIH) and ENG. CEMMSS also includes CISE investments (along with EHR, ENG, and SBE) in NRI (together with DARPA, NASA, NIH, and USDA). As part of this research activity, CISE will synergize investments across multiple research communities and programs in order to transform static systems, processes, and edifices into adaptive, pervasive smart systems with embedded computational intelligence that can sense, adapt, and react.

- Advanced Manufacturing: As part of CEMMSS, CISE, in partnership with ENG and MPS, will invest in research that integrates ubiquitous sensors, computational tools, and highly connected cyber-physical systems in smart processing and cyber manufacturing systems. This investment will result in higher quality products with greater efficiency and sustainability produced by the factories of the future. CISE will also invest in basic research to advance robotics technology, enabling new functionalities and providing the next-generation of products and services in various industries. This includes co-robots that work alongside or cooperatively with people in manufacturing environments to increase their productivity, performance, and safety.

- Clean Energy Technology: CISE will support foundational research in energy-intelligent computing; the development of new theory, algorithms, and design principles to investigate energy versus computation and communication tradeoffs; and the scalability and sustainability of smart energy production software and hardware. CISE research on clean energy is partially supported via investments in INFEWS.

- CIF21: CISE will continue to lead CIF21 through investments in the Big Data, DIBBs, SI^2, EarthCube, and CDS&E programs. Big Data research will focus on core scientific and technological means of managing, analyzing, visualizing, and extracting useful information from large, distributed, and heterogeneous data sets as well as applications in specific research domains. DIBBs aims to develop, implement, and support new cyberinfrastructure to store and manage the diversity, size, and complexity of current and future data sets and streams. To advance new computational infrastructure, SI^2 promises to advance new paradigms and practices in the development and use of robust, reliable, usable, and sustainable software. CISE will increase funding in partnership with other directorates in Data Science Pilots to increase the Nation's capacity in data science.

- I-Corps™: CISE will continue to support I-Corps™ Teams, Sites, and Nodes to further build, utilize, and sustain a national innovation ecosystem that continues to augment the development of technologies, products, and processes that benefit the Nation. CISE's investment will seek to identify NSF-funded researchers who will receive additional support in the forms of mentoring and funding to accelerate innovation that can attract subsequent third-party investment.

- NSF INCLUDES: CISE will participate in NSF INCLUDES, the NSF-wide effort to increase the preparation, participation, advancement, and potential contributions of those who have been traditionally underserved and/or underrepresented in STEM fields.

- INFEWS: CISE will support research in the security and protection of the food-energy-water nexus through investments in new resource management algorithms and architectures; real-time

coordination and communications; robust observation, sensing, and inference; large-scale data analysis and management, including modeling and simulation; and optimization of complex systems. A portion of this funding will be directed toward Advanced Computational Infrastructure, providing additional resources in support of research on INFEWS.

- NSF Research Traineeship (NRT): CISE will continue to fund STEM graduate students in interdisciplinary areas of national priority, and to support the development of transformative and scalable models for STEM graduate education. CISE funding for FY 2015 Estimate includes funding to support awards that could not be made during FY 2014.

- Risk and Resilience: In partnership with ENG and SBE, CISE supports the science and engineering necessary to enable advances in large-scale resilient and interdependent infrastructures.

- SaTC: NSF continues to align its cybersecurity investments (including investments from EHR, ENG, MPS, and SBE) with the national cybersecurity strategy, *Trustworthy Cyberspace: Strategic Plan for the Federal Cybersecurity Research and Development Program.*[2] SaTC aims to support scientific foundations, induce change, maximize research impact, and accelerate the transition of advances to practice. CISE is collaborating with EHR to support cyber-secure workforce development to enable a growing pipeline of researchers and educators, and to develop a citizenry that understands the security and privacy of the digital systems on which society depends. This investment also includes support for the Comprehensive National Cybersecurity Initiative (CNCI) ($48.0 million).[3]

- Understanding the Brain: In collaboration with other NSF directorates and offices, CISE will support projects focused on understanding the brain. In particular, CISE will support projects that develop computational approaches for investigating neural and behavioral plasticity in response to external changes. CISE investments will enable the research needed to integrate computational models across scales; the development of innovative neurotechnologies to monitor brain function; and the expansion of the capacity of neuroscience infrastructure to integrate data across levels of analysis from molecular to behavioral scales. A portion of this funding will be directed toward Advanced Computational Infrastructure, providing additional resources in support of research on Understanding the Brain.

- Urban Science: In collaboration with ENG and SBE, CISE will support a new NSF-wide multidisciplinary activity in urban science. This investment will focus on the research and development of critical infrastructure and applications, which address pressing urban challenges, such as sustainability, livability, and equity, through both fundamental research and translational research that is supported via partnerships. Multidisciplinary urban science research efforts at NSF will address the question of how cities can be intelligently and effectively designed, adapted, and managed to maximize their positive potential. Support for urban sciences will enable the integration of networked computing systems, physical devices, data sources, and infrastructure leading to smart cities.

[2] www.whitehouse.gov/sites/default/files/microsites/ostp/fed_cybersecurity_rd_strategic_plan_2011.pdf
[3] www.whitehouse.gov/issues/foreign-policy/cybersecurity/national-initiative

CISE Funding for Centers Programs and Facilities

CISE Funding for Centers Programs

(Dollars in Millions)

	FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	Change Over FY 2015 Estimate Amount	Change Over FY 2015 Estimate Percent
Total, Centers Programs	**$10.00**	**$10.00**	**$10.00**	**-**	**-**
STC: The Center for Science of Information (CCF)	5.00	5.00	5.00	-	-
STC: The Center for Brains, Minds and Machines (CCF, IIS, ITR)	5.00	5.00	5.00	-	-

Totals may not add due to rounding.

For detailed information on individual centers, please see the NSF-wide Investments chapter.

- CISE will provide the sixth year of funding for the STC Center for Science of Information at Purdue University. The goal of this center is to develop a new science of information, incorporating common features associated with data/information, such as space, time, structure, semantics, and context, but which are not addressed by earlier mathematical theories, e.g., data obfuscation and hiding techniques. This new science of information will enhance robustness and the principles of redundancy and fault tolerance found in natural systems.

- CISE will provide the fourth year of funding for the STC Center for Brains, Minds and Machines: The Science and the Technology for Intelligence at MIT. This center has five main research themes: circuits for intelligence; the development of intelligence in children; social intelligence; the integration of visual, motor, language, and social intelligence; and theoretical aspects of intelligence.

CISE Funding for Facilities

(Dollars in Millions)

	FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	Change Over FY 2015 Estimate Amount	Change Over FY 2015 Estimate Percent
Total, Facilities	**$0.60**	**$0.60**	**$0.60**	**-**	**-**
National Nanotechnology Infrastructure Network (CCF)	0.60	-	-	-	N/A
National Nanotechnology Coordinated Infrastructure (CCF)	-	0.60	0.60	-	-

Totals may not add due to rounding.

For detailed information on individual facilities, please see the Facilities chapter.

Summary and Funding Profile

CISE supports investments in core and interdisciplinary research and education, as well as in computing research infrastructure.

In FY 2016, the number of research grant proposals is expected to increase by approximately 7.7 percent compared to the FY 2015 Estimate. CISE expects to award approximately 1,640 research grants in FY 2016. Average annualized award size and average award duration are expected to remain constant between the FY 2015 Estimate and FY 2016 Estimate.

Funding for research infrastructure represents 17.6 percent of the CISE Request. Most of CISE's research infrastructure support is for High Performance Computing (HPC) (see Appendix A for more information on the HPC portfolio).

CISE Funding Profile

	FY 2014 Actual Estimate	FY 2015 Estimate	FY 2016 Estimate
Statistics for Competitive Awards:			
Number of Proposals	7,436	7,800	8,400
Number of New Awards	1,682	1,820	1,970
Funding Rate	23%	23%	23%
Statistics for Research Grants:			
Number of Research Grant Proposals	7,094	7,440	8,010
Number of Research Grants	1,407	1,520	1,640
Funding Rate	20%	20%	20%
Median Annualized Award Size	$166,122	$165,000	$165,000
Average Annualized Award Size	$199,367	$210,000	$210,000
Average Award Duration, in years	2.9	3.0	3.0

Program Monitoring and Evaluation

Committees of Visitors (COV)

- In early FY 2015, CISE convened a Committee of Visitors (COV) to examine and assess the quality of the merit review process across three of its divisions – CCF, CNS, and IIS. The CISE Advisory Committee subsequently accepted the COV report. CISE is not holding any COVs in FY 2016.

Science and Technology Policy Institute (STPI) Reports and Evaluations

- In FY 2012, the Science and Technology Policy Institute (STPI) was tasked to conduct program evaluation feasibility studies for the SaTC and CEMMSS programs. These feasibility studies are providing methods for examining baseline portfolio investments and identifying metrics to measure progress toward program goals. They are part of a broader effort to develop a plan for impact assessments of SaTC and CEMMSS investments. The preliminary work to identify baseline evaluation metrics was conducted in FY 2013 – FY 2014, and it is anticipated that further program evaluation analyses will continue in FY 2016. Yearly program-wide analyses will be presented to the CEMMSS and SaTC working groups and to NSF senior management.

STEM Evaluation

- Evaluation is also a vital part of CISE's STEM education programs. Each of the STEM + C Partnerships projects managed by CISE has a rigorous research and/or evaluation plan designed to guide project progress and measure its impact. These plans include descriptions of the instruments and metrics that are to be used. Across the STEM + C Partnerships portfolio managed by CISE, a set of common metrics and a design for evaluation instruments are being developed. The initial design is complete, and the first program evaluation is expected to be under contract by FY 2016.

Reports

- CISE funded the National Academy of Sciences (NAS) Computer Science and Telecommunications Board (CSTB) to study the IT innovation ecosystem and to assess the long-term economic impacts of CISE investments. The report, *Assessing the Impacts of Changes in the Information Technology R&D Ecosystem,*[4] published in 2009, includes an in-depth articulation of the creation of almost 20 IT industries, since 1965, valued at a minimum of a billion dollars each. To update this study, CISE funded CSTB to identify recent IT industries that have reached the billion dollar mark; develop a brief report that highlights the updated figures; and summarize results-to-date of IT research, including the nature and successes of U.S. research partnerships among government, industry, and universities, and the economic payoffs of these research investments. The resulting report, *Continuing Innovation in Information Technology,* was published in 2012.[5] The framework in the report is being employed as part of a current CSTB study, *Continuing Innovation in Information Technology: A Workshop* (described below).
- In FY 2012, a CSTB study, *The Future of Computing Performance: Game Over or Next Level?,*[6] together with a white paper from the CISE-funded Computing Community Consortium (CCC), *21st Century Computer Architecture,*[7] outlined the need for advances in computer architecture research which led to the development of the XPS program that was initiated in FY 2013.
- In FY 2013, the CCC collected community white papers articulating the potential needs and payoff for additional investments in mid-scale infrastructure for computing research[8] which led to the development of the NSFFutureCloud program started in FY 2014.
- In FY 2014 through FY 2015, the CCC led a Computing Visions 2025 initiative, intended to inspire the computing community to envision future trends and opportunities in computing research. Two workshops were held under this initiative: *Interacting with Computers All Around Us*, and *The New Making Renaissance: Programmable Matter and Things.* These workshops have the potential to influence the development of CISE programs in FY 2016. In addition, two other ongoing workshop activities led by the CCC are contributing to an understanding of the role of IT in home management of chronic diseases, and in opportunities at the intersection of computer science and brain science.
- CISE also funded four CSTB studies that are currently ongoing and have the potential to influence the development of CISE programs in FY 2016.
    - *Continuing Innovation in Information Technology: A Workshop:* will conduct a public workshop that highlights additional examples of the impacts of computing research using the framework established in the "tiretracks" figure published in CSTB's 2012 report *Continuing Innovation in Information Technology* and explore further uses of the figure and framework.
    - *A Primer on Cybersecurity: Leveraging Two Decades of National Academies Work*: will examine what is known about effective technical and nontechnical approaches, the state of the art and open challenges, why relatively little progress has been made in cybersecurity despite the recommendations of many reports from the Academies and elsewhere, and potential policy

[4] www.nap.edu/catalog.php?record_id=12174
[5] www.nap.edu/catalog.php?record_id=13427
[6] www.nap.edu/openbook.php?record_id=12980
[7] http://cra.org/ccc/docs/init/21stcenturyarchitecturewhitepaper.pdf
[8] http://cra.org/ccc/visioning/visioning-activities/mid-scale-infrastructure-investments-for-computing-research

responses.

- *Toward 21st-Century Cyber-Physical Systems Education*: will conduct a study on the current and future needs in education for cyber-physical systems (CPS) and articulate a vision for a 2lst century CPS-capable U.S. workforce.
- *Future Directions for NSF Advanced Computing Infrastructure to support U.S. Science in 2017-2020:* will examine anticipated priorities and associated tradeoffs for advanced computing in support of NSF-sponsored science and engineering research.

The Performance chapter provides details regarding the periodic reviews of programs and portfolios of programs by external Committees of Visitors and directorate Advisory Committees. Please see this chapter for additional information.

Number of People Involved in CISE Activities

	FY 2014 Actual Estimate	FY 2015 Estimate	FY 2016 Estimate
Senior Researchers	6,663	6,900	7,100
Other Professionals	1,123	1,200	1,200
Postdoctorates	491	500	500
Graduate Students	6,064	6,300	6,500
Undergraduate Students	2,433	2,500	2,600
Total Number of People	**16,774**	**17,400**	**17,900**

DIVISION OF ADVANCED CYBERINFRASTRUCTURE (ACI) $227,290,000
+$8,490,000 / 3.9%

ACI Funding
(Dollars in Millions)

	FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	Change Over FY 2015 Estimate Amount	Change Over FY 2015 Estimate Percent
Total, ACI	**$211.93**	**$218.80**	**$227.29**	**$8.49**	**3.9%**
Research	**79.56**	**96.30**	**97.79**	**1.49**	**1.5%**
CAREER	3.02	3.10	3.30	0.20	6.5%
Education	**4.83**	**8.70**	**5.70**	**-3.00**	**-34.5%**
Infrastructure	**127.53**	**113.80**	**123.80**	**10.00**	**8.8%**
Networking and Computational Resources Infrastructure and Services	127.53	113.80	123.80	10.00	8.8%

Totals may not add due to rounding.

ACI supports the advance of science and engineering research and education by exploring, developing, creating, and supporting secure, advanced, and global cyberinfrastructure (CI). ACI partners with other CISE divisions and NSF directorates and offices to support research and development across the entire range of cyberinfrastructure activities required to advance scientific and engineering frontiers. This includes the acquisition, integration, coordination, and operations associated with data, networking, computation, software, and the development of CDS&E tools and expertise. ACI focuses on the development of these resources and capabilities, as well as on the expertise to conduct next-generation science and engineering, in order to address complex and multidisciplinary discovery, prediction, and innovation. ACI provides computational support to more than 8,000 faculty and researchers, and supports international activities in networking, software, data, and computation, including connectivity to major international resources and scientific instruments. ACI also fosters relationships with other federal agencies and international research funding agencies with shared scientific priorities to promote collaborative research cyberinfrastructure.

In general, 41 percent of the ACI portfolio is available for new grants and 59 percent is available for continuing grants.

Approximately 60 percent of ACI's budget is used to support individuals and small groups of researchers. The remaining 40 percent of the budget goes toward the support of larger cyberinfrastructure consortia, including the eXtreme Digital (XD) services program, the Blue Waters Petascale Computing Program, and mid-scale pilots and prototypes toward an integrated data infrastructure.

FY 2016 Summary

All funding decreases/increases represent change over the FY 2015 Estimate.

Research

- ACI will continue to support early-career researchers through increased investments in the CAREER program (+$200,000 to a total of $3.30 million).

- In partnership with ENG, GEO, MPS, SBE, and other CISE divisions, ACI will continue to enable advances in large-scale resilient, secure, and interoperable research cyberinfrastructure through the Risk and Resilience investment area (+$500,000, to a total of $3.0 million).
- ACI will invest in the NSF-wide priority area INFEWS (+$500,000 to a total of $500,000), as part of increased support for Clean Energy Technology (+$100,000 to a total of $3.60 million). ACI will focus on the exploration of new robust, integrative approaches to sustainable software and data cyberinfrastructure to advance multidisciplinary computational and data science for food, water, and energy security research and education.
- ACI will continue to provide leadership for CIF21 ($62.71 million). This leadership includes developing coordinated CIF21 programs and solicitations, and identifying common approaches for a scalable, comprehensive cyberinfrastructure. ACI will invest in multidisciplinary data and software programs, such as CDS&E, EarthCube, SI^2, and DIBBS, including Data Science Pilots that will be undertaken in partnership with other NSF directorates.

Education

- ACI will continue support for the NSF Research Traineeship program (-$2.50 million to a total of $3.0 million) to encourage the development of bold, new, potentially transformative, and scalable models for STEM graduate training focusing on areas of national priority.
- ACI will maintain its investments in the STEM + C Partnerships ($500,000), which seek to enhance computational competencies for students and teachers.
- Along with the other CISE divisions, ACI will maintain support for REU sites and supplements ($1.20 million).

Infrastructure

- ACI will increase its data and computational capacity (+$10.0 million to a total of $123.80 million) to support multidisciplinary research in NSF priority areas, including INFEWS and UtB. The need for increased data and computational capacity is driven by the growing set of collaborative, multidisciplinary research teams and communities as well as the growth of both simulations and data analytics for scientific discovery. The following investments are part of ACI's support for Networking and Computational Resources Infrastructure and Services:
  - Advanced computing investment (+$6.0 million to a total of $80.65 million). This will include the combined services and resources of XD, operating a virtual computational environment for more than 8,000 scientists and engineers, and the Blue Waters sustained petascale resource that allows computational scientists in a variety of domains, such as molecular dynamics, protein folding, cosmology, climate modeling, and earthquake modeling, to retain international competitiveness by addressing some of the most difficult research problems known today (see Appendix A for more information on the HPC portfolio).
  - Investments in transition to practice within SaTC ($3.0 million). Advanced, secure networking and data sharing are increasingly important to support research collaborations and facilitate multidisciplinary research and education.

DIVISION OF COMPUTING AND COMMUNICATION FOUNDATIONS (CCF) — $198,590,000 / +$7,260,000 / 3.8%

CCF Funding
(Dollars in Millions)

	FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	Change Over FY 2015 Estimate Amount	Change Over FY 2015 Estimate Percent
Total, CCF	**$184.88**	**$191.33**	**$198.59**	**$7.26**	**3.8%**
Research	**174.22**	**180.13**	**188.39**	**8.26**	**4.6%**
CAREER	13.97	13.67	14.36	0.69	5.0%
Centers Funding (total)	9.00	8.00	8.00	-	-
STC: The Center for Science of Information	5.00	5.00	5.00	-	-
STC: The Center for Brains, Minds and Machines	4.00	3.00	3.00	-	-
Education	**10.06**	**10.60**	**9.60**	**-1.00**	**-9.4%**
Infrastructure	**0.60**	**0.60**	**0.60**	**-**	**-**
National Nanotechnology Coordinated Infrastructure (NNCI)	-	0.60	0.60	-	-
National Nanotechnology Infrastructure Network (NNIN)	0.60	-	-	-	N/A

Totals may not add due to rounding.

CCF supports research and education activities that explore the foundations and limits of computation, communication, and information; advance algorithmic knowledge for research areas both within and outside computer science; and advance software, hardware, and computer system design. CCF's research investments support advances in the design and analysis of algorithms; computational complexity, theoretical and experimental studies of algorithms and their resource requirements; and formal models of computation. These research investments include models for parallel, distributed, and heterogeneous multi-core machines. CCF invests in research addressing the theoretical underpinnings and enabling technologies for information acquisition, transmission, and processing in communication and information networks, such as sensor, wireless, multimedia, and biological networks. CCF investments advance the design, verification, evaluation, and utilization of computing hardware and software through new theories and tools that focus on performance, correctness, usability, dependability, reliability, and scalability. CCF also invests in research that explores the potential impact of emerging technologies on computation and communication, including nanotechnology, biotechnology, and quantum devices and systems.

In general, 76 percent of the CCF portfolio is available for new research grants and 24 percent is available for continuing grants.

FY 2016 Summary

All funding decreases/increases represent change over the FY 2015 Estimate.

Research

- CCF will continue to support early-career researchers through increased investments in the CAREER program (+$690,000 to a total of $14.36 million).

- CCF will invest in the NSF-wide priority area INFEWS (+$3.50 million to a total of $3.50 million), as part of increased support for Clean Energy Technology (+$720,000 to a total of $11.72 million). CCF will focus on foundational research in energy-intelligent computing, leading to novel approaches for large-scale data analysis and management; and innovative optimization techniques, algorithms and software development.
- CCF will increase its investments in the NSF-wide priority area UtB (+$2.50 million to a total of $8.25 million) through investments in core and crosscutting research, including integrating computational models across multiple scales, from molecules to systems, toward accomplishing the ultimate goal of establishing an integrative, quantitative, and predictive theory of brain function.
- CCF will continue to support the NSF-wide CEMMSS program through CPS ($5.50 million) and NRI ($3.0 million). This investment will emphasize development of new methods for specification and verification of software and hardware systems useful for various sectors including cyber manufacturing.
- CCF will maintain its current level of support for SaTC ($14.25 million) through investments in theories, models, algorithms, architectures, languages and tools for increased security, privacy and trust, as well as in new cryptographic approaches for hardware assurance.
- CCF will continue to support CIF21 ($8.25 million). CCF will emphasize its investments in Big Data foundational research, including algorithms and software tools for handling large and heterogeneous data sets; randomized streaming algorithms, which are scalable and extremely efficient for Big Data; methods for validating data; and tools for extracting knowledge to enable new discoveries.
- CCF will maintain its current investment level of support for the Algorithms in the Field (AitF) program ($4.0 million). The AitF program promotes closer collaboration between theoretical computer science researchers, who focus on the design and analysis of provably efficient and correct algorithms, and applied researchers, including systems and domain experts.
- CCF will maintain the current investment level of support for the XPS program ($6.50 million). Through XPS, CCF supports research into new and visionary approaches to re-evaluate and possibly re-design the traditional computer hardware and software stack for today's heterogeneous parallel, concurrent, and distributed systems, and investigates new holistic approaches to parallelism and cross-layer design.
- CCF will continue to support two STCs, the Center for Science of Information at Purdue University ($5.0 million) and the Center for Brains, Minds and Machines: The Science and the Technology of Intelligence at MIT ($3.0 million). The CISE investment in the MIT Center ($5.0 million) is shared with the IIS and ITR divisions.

Education

- CCF will continue to support the NSF Research Traineeship program (-$1.0 million to a total of $1.50 million) to encourage the development of bold, new, potentially transformative, and scalable models for STEM graduate training focusing on areas of national priority.
- CCF will maintain its investments in the STEM + C Partnerships ($4.0 million), which seek to enhance computational competencies for students and teachers.
- Along with the other CISE divisions, CCF will maintain support for REU sites and supplements ($3.25 million).

Infrastructure

- CCF will fund the National Nanotechnology Coordinated Infrastructure (NNCI) ($600,000), supported primarily by ENG. NNCI is the successor to the National Nanotechnology Infrastructure Network (NNIN).

DIVISION OF COMPUTER AND NETWORK SYSTEMS (CNS) $236,320,000
+$8,660,000 / 3.8%

CNS Funding

(Dollars in Millions)

	FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	Change Over FY 2015 Estimate Amount	Change Over FY 2015 Estimate Percent
Total, CNS	**$220.02**	**$227.66**	**$236.32**	**$8.66**	**3.8%**
Research	**176.83**	**181.70**	**192.05**	**10.35**	**5.7%**
CAREER	12.29	13.33	14.01	0.68	5.1%
Education	**15.57**	**15.96**	**14.27**	**-1.69**	**-10.6%**
Infrastructure	**27.61**	**30.00**	**30.00**	**-**	**-**
Research Resources	27.61	30.00	30.00	-	-

Totals may not add due to rounding.

CNS supports research and education activities that advance understanding of the fundamental properties of computer systems and networks; explore new ways to make better use of existing computer systems and networks; and develop novel paradigms, abstractions, and tools for designing, analyzing, and building next-generation computer systems and networks that are robust, secure, and trustworthy. CNS investments include, but are not limited to, cyber-physical, embedded, cloud computing, wearable, and "smart dust" systems. CNS investments in fundamental network research create new insights into the dynamics of complex networks, and explore new architectures for future-generation networks and services. CNS provides scientific leadership in cybersecurity, supporting research and education activities that will ensure society's ubiquitous computing and communications systems deliver the quality of service they are designed to achieve without disruption, while enabling and preserving privacy, security, and trust. CNS also plays a leadership role in coordinating CISE investments in research infrastructure resources and in the development of the computing workforce of the future.

In general, 65 percent of the CNS portfolio is available for new grants and 35 percent is available for continuing grants.

FY 2016 Summary

All funding decreases/increases represent change over the FY 2015 Estimate.

Research

- CNS will continue to support early-career researchers through increased investments in the CAREER program (+$680,000 to a total of $14.01 million).
- In partnership with EHR, ENG, MPS, SBE, and the other CISE divisions, CNS will continue to lead SaTC (+$500,000 to a total of $44.30 million), which aligns with the Comprehensive National Cybersecurity Initiative (CNCI). Through SaTC, CNS will invest in areas of current critical importance such as network and cloud security, cybereconomics, and science of security and of privacy. These investments also will address education and workforce issues related to cybersecurity.
- In partnership with four other federal agencies (DHS, DOT, NASA, and NIH), ENG, and other CISE divisions, CNS will continue to lead the CPS program ($23.0 million). As a critical underpinning of CEMMSS, CNS will support foundational interdisciplinary research and education in adaptive and pervasive smart systems such as cyber manufacturing, smart grid technologies, and medical devices. CNS will also continue its investments in NRI ($4.50 million).

- CNS will participate in the NSF-wide investment INFEWS (+$3.25 million to a total of $3.25 million), as part of increased support for clean energy technology (+$500,000 to a total of $4.50 million). CNS will focus its support on foundational systems research in energy-intelligent computing, leading to novel approaches for robust observation, sensing, and inference. CNS will also invest in research related to control, automation, and optimization of the complex systems underlying the nexus of food, energy, and water.
- In partnership with ENG, GEO, MPS, SBE, and other CISE divisions, CNS will continue to support the science and engineering needed to enable advances in large-scale resilient and interdependent infrastructures through the Risk and Resilience investment area (+$1.0 million to a total of $5.0 million).
- CNS will support the NSF-wide priority area UtB ($1.5 million) by investing in core and crosscutting research in neurotechnology development, as well as in building innovative pilot infrastructure and analytic tools for data integration across scales and disciplines.
- In partnership with ENG, SBE, and other CISE divisions, CNS will support activities focused on multidisciplinary urban science (+$2.0 million to a total of $2.50 million), enabling effective integration of networked computing systems, data sources, and infrastructure underlying smart cities.
- CNS will continue to support CIF21 ($3.75 million) through investments in foundational systems research advancing the science of big data, including middleware, tools, and networking support for managing massive amounts of heterogeneous, complex, and real-time data.
- CNS will continue investing in US Ignite ($2.50 million) by developing innovative public-sector gigabit applications that leverage or enhance advanced networking technologies in support of national priority areas.

Education

- CNS will invest in NSF INCLUDES (+$1.0 million to a total of $1.0 million) to increase the preparation, participation, advancement, and potential contributions of those who have been traditionally underserved and/or underrepresented in STEM.
- CNS will maintain its investments in the STEM + C Partnerships, which seek to enhance computational competencies for all students ($4.0 million). This program will enlarge the pool of K-14 students and teachers who develop and practice computational competencies in a variety of contexts, as well as the pool of early postsecondary students who are engaged and have the background in computing necessary to successfully pursue degrees in computing-related and computationally-intensive fields of study.
- Along with the other CISE divisions, CNS will maintain support for REU sites and supplements ($4.48 million).
- CNS will continue to support the NSF Research Traineeship program (-$690,000 to a total of $990,000) to encourage the development of bold, new, potentially transformative, and scalable models for STEM graduate training focusing on areas of national priority.

Infrastructure

- Through the CISE Research Infrastructure (CRI) program ($18.0 million), CNS supports acquisition, enhancement, community access, and operation of state-of-the-art computing research infrastructure enabling high-quality computing research and education across a diverse range of institutions.
- CNS will maintain support for the development of world-class, mid-scale network infrastructure ($9.50 million), including NSFFutureCloud, providing programmable testbeds for experimenting with novel cloud architectures addressing emerging challenges such as high-confidence systems.
  CNS will continue to support US Ignite ($2.50 million) to integrate additional U.S. cities/regions and create a unique at-scale infrastructure, enabling multi-city/regional testbeds and “Living Labs” that facilitate building and experimenting with advanced public-sector gigabit networking applications that address national priorities.

DIVISION OF INFORMATION AND INTELLIGENT SYSTEMS (IIS) — $198,940,000 +$7,290,000 / 3.8%

IIS Funding

(Dollars in Millions)

	FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	Change Over FY 2015 Estimate Amount	Change Over FY 2015 Estimate Percent
Total, IIS	**$184.87**	**$191.65**	**$198.94**	**$7.29**	**3.8%**
Research	**173.72**	**181.85**	**189.14**	**7.29**	**4.0%**
CAREER	20.11	15.40	16.11	0.71	4.6%
Centers Funding (total)	-	1.00	1.00	-	-
STC: The Center for Brains, Minds and Machines	-	1.00	1.00	-	-
Education	**11.15**	**9.80**	**9.80**	**-**	**-**

Totals may not add due to rounding.

IIS supports research and education to develop and apply new IT to enhance the capabilities of people and machines to create, discover, and reason by advancing their ability to represent, collect, store, organize, visualize, and communicate data and information; to develop new knowledge to support people in the design and use of IT; and to advance knowledge about how computational systems can perform tasks autonomously, robustly, and flexibly.

IIS research investments support the exploration of novel theories and innovative technologies that advance understanding of the complex and increasingly coupled relationships between people and computing, and promise to enhance quality of life. Investments in information integration and informatics focus on the processes and technologies involved in creating, managing, visualizing, and fusing diverse data, information, and knowledge from disparate and uncoordinated sources within a changing landscape of computing platforms, from personal devices to globally-distributed networks. IIS also invests in research on artificial intelligence, computer vision, natural language, robotics, machine learning, computational neuroscience, cognitive science, and areas leading to the computational understanding and modeling of intelligence in complex, realistic contexts. These investments aim to revolutionize understanding of brain functions.

In general, 71 percent of the IIS portfolio is available for new research grants and 29 percent is available for continuing grants.

FY 2016 Summary

All funding decreases/increases represent change over the FY 2015 Estimate.

Research

- IIS will continue to support early-career researchers through increased investments in the CAREER program (+$710,000 to a total of $16.11 million).
- IIS will increase its investments in the NSF-wide priority area UtB (+$4.58 million to a total of $13.83 million) by supporting core and crosscutting research in developing novel computational tools for performing multi-scale analysis of physiological, cognitive, and behavioral data, and innovative models that will accelerate the integration of knowledge across scales from molecules to systems and across multiple disciplines. This research aims to accelerate the formulation of an integrative, quantitative, and predictive theory of brain function.

- IIS will participate in the NSF-wide investment INFEWS (+$1.25 million to a total of $1.25 million), as part of increased support for clean energy technology (+$250,000 to a total of $2.75 million). IIS will focus on novel approaches for large-scale data analysis and management will bring together multidisciplinary researchers, particularly in real-time data analytics and artificial intelligence.
- IIS will continue to support the NSF-wide investment CEMMSS. In partnership with four other federal agencies (DARPA, NASA, NIH, and USDA), three other NSF directorates (ENG, SBE, and EHR), and other CISE divisions, IIS will continue to lead the NRI program ($13.0 million). NRI, a component of CEMMSS, focuses on human-centered research in developing service robots; this requires significant advances in human-robot interaction. Application domains include robots as co-workers in advanced manufacturing environments, aides supporting emergency responders in the field, and service robots assisting the elderly to live independently. IIS will also focus on fundamental research in robotics, including advanced sensing, control, and power sources; integrated problem-solving architectures and decision algorithms; and safe and soft structures. As part of its CEMMSS investment, IIS will also continue its investments in CPS ($4.50 million).
- IIS will continue to invest in CIF21 ($9.50 million). In partnership with other NSF directorates and CISE divisions, IIS will lead Big Data research activities to address challenges in the management of data and knowledge, to devise computational methods for data analysis, and to automate many aspects of data-enabled discovery processes, while ensuring appropriate security and privacy guarantees.
- In partnership with six NIH institutes, ENG, SBE, and other CISE divisions, IIS will continue to lead the Smart and Connected Health program ($9.0 million). IIS will pursue improvements in safe, effective, efficient, and patient-centered proactive and predictive health and wellness technologies. This program addresses changing age demographics with investments in assistive, engineered cyber-physical systems.
- IIS will continue to lead the Cyberlearning program ($9.75 million) with EHR, ENG and other CISE divisions. This activity will integrate advances in technology with advances in the ways people learn; resolve how to more effectively use technology for promoting learning; and design new technologies for integration in learning environments and evaluate their use. Interdisciplinary teams will study the deluge of data produced from new on-line teaching paradigms to better understand learning mechanisms and enable productive, personalized, customized, and privacy-preserving education.
- As part of its investment in SaTC ($8.95 million), IIS will continue to support research in cyber-security and privacy, with an emphasis on data science, usability, socio-technical, and human-centered approaches.
- IIS will provide support for the STC Center for Brains, Minds and Machines: The Science and the Technology of Intelligence at MIT ($1.0 million) along with the CCF and ITR divisions.

Education

- IIS will continue support for the NSF Research Traineeship program ($1.0 million) to encourage the development of bold, new, potentially transformative, and scalable models for STEM graduate training focusing on areas of national priority.
- IIS will maintain its investments in the STEM + C Partnerships ($4.0 million), which seek to enhance computational competencies for students and teachers.
- Along with the other CISE divisions, IIS will maintain support for REU sites and supplements ($3.95 million).

DIVISION OF INFORMATION TECHNOLOGY RESEARCH (ITR) — $93,270,000 / +$980,000 / 1.1%

ITR Funding

(Dollars in Millions)

	FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	Change Over FY 2015 Estimate Amount	Change Over FY 2015 Estimate Percent
Total, ITR	**$90.91**	**$92.29**	**$93.27**	**$0.98**	**1.1%**
Research	**79.16**	**75.84**	**75.54**	**-0.30**	**-0.4%**
CAREER	0.46	-	-	-	N/A
Centers Funding (total)	-	1.00	1.00	-	-
STC: The Center for Brains, Minds and Machines	-	1.00	1.00	-	-
Education	**0.13**	**2.95**	**4.23**	**1.28**	**43.4%**
Infrastructure	**11.62**	**13.50**	**13.50**	**-**	**-**
Research Resources	11.62	13.50	13.50	-	-

Totals may not add due to rounding.

ITR provides support for transformative explorations in computer and information science and engineering research, infrastructure, and related education activities, emphasizing the funding of high-risk, multi-investigator, and multidisciplinary projects.

In general, 40 percent of the ITR portfolio is available for new grants and 60 percent is available for continuing grants.

FY 2016 Summary

All funding decreases/increases represent change over the FY 2015 Estimate.

Research

- Through I-Corps™ (+$650,000 to a total of $11.65 million), ITR will invest in NSF-funded researchers who will receive additional support – in the form of mentoring and funding – to accelerate innovation and transfer of knowledge from lab to practice. ITR will also invest in I-Corps™ Sites and Nodes to further build, utilize, and sustain a national innovation ecosystem that continues to augment the development of technologies, products, and processes that benefit the Nation.
- In partnership with ENG, SBE, and other CISE divisions, ITR will support activities focused on multidisciplinary urban science (+$500,000 to a total of $1.0 million), enabling effective integration of networked computing systems, physical devices, data sources, and infrastructure that leads to smart cities.
- ITR will continue its investment in US Ignite ($2.50 million) by developing innovative public-sector gigabit applications that leverage or enhance advanced networking technologies in support of national priority areas.
- In collaboration with ENG, CISE will maintain support for innovative partnerships and collaborations between universities and industries, in part through the Industry/University Cooperative Research Centers (I/UCRC) program, which will continue to establish centers that partner industry with university research efforts ($8.0 million).

- ITR will maintain its investments in the center-scale Expeditions in Computing program ($12.0 million). This program identifies projects with transformative research agendas that promise to accelerate discovery at the frontiers of computing and communication.
- ITR will invest in multi-disciplinary research networks, including support for the Science Across Virtual Institutes (SAVI) activity ($2.0 million). These research networks will provide opportunities to develop collaborations in areas of emerging interest to computer and information science and engineering, including international partnerships.
- ITR will continue to provide support for emerging and urgent high-priority areas of potentially transformative research through various award mechanisms, such as EArly-concept Grants for Exploratory Research (EAGERs) and Grants for Rapid Response Research (RAPIDs), and through co-funding of awards with other NSF directorates to pursue important emerging areas.
- ITR will maintain support ($1.0 million) for the STC Center for Brains, Minds and Machines: The Science and the Technology of Intelligence at MIT along with the CCF and IIS divisions.

Education

- ITR will continue support for the NSF Research Traineeship program (+$500,000 to a total of $3.20 million) to encourage the development of bold, new, potentially transformative, and scalable models for STEM graduate training focusing on areas of national priority.
- ITR will invest in NSF INCLUDES (+$780,000 to a total of $780,000) to increase the preparation, participation, advancement, and potential contributions of those who have been traditionally underserved and/or underrepresented in STEM.

Infrastructure

- ITR will continue to support US Ignite ($2.50 million) to integrate additional U.S. cities/regions and create a unique at-scale infrastructure, enabling multi-city/regional testbeds and "Living Labs" that facilitate building and experimenting with advanced public-sector gigabit networking applications that address national priorities.
- ITR will extend virtualization beyond the network to large-scale, interconnected computing resources by continuing to develop mid-scale prototypes for an NSFFutureCloud research infrastructure, providing programmable testbeds for experimenting with novel cloud architectures addressing emerging challenges such as high-confidence systems ($6.0 million).

APPENDIX A – HIGH PERFORMANCE COMPUTING PORTFOLIO

High Performance Computing Funding

(Dollars in Millions)

	Total of Prior Years	FY 2014 Actual	FY 2015 Estimate	FY 2016 Request
Petascale (Track 1)	$299.64	$55.38	$21.65	$28.65
Innovative HPC Program	213.38	27.79	30.00	25.00
Teragrid - Phase III (XD)	142.54	13.55	23.00	27.00
Total	**$655.56**	**$96.72**	**$74.65**	**$80.65**

Totals may not add due to rounding.

NSF has been a leader in the use of High Performance Computing (HPC) to advance discovery for almost four decades. As a result of continuous rapid changes in computing and related technologies, coupled with the exponential growth and complexity of data for the science, engineering, and education enterprise, NSF developed a new vision and strategy for Advanced Computing Infrastructure (ACI), which expands NSF's leadership role in science and engineering. This coordinated NSF-wide strategy, entitled *Cyberinfrastructure for 21st Century Science and Engineering: Advanced Computing Infrastructure,*[9] is a key component of the Cyberinfrastructure Framework for 21st Century Science, Engineering, and Education (CIF21). This strategy seeks to position and support the entire spectrum of NSF-funded communities at the cutting edge of advanced computing technologies, hardware, and software, and aims to promote a more complementary, comprehensive, and balanced portfolio of advanced computing infrastructure and programs for research and education. The strategy enables multidisciplinary computational- and data-enabled science and engineering that supports all science, engineering, and education communities. This shift is consistent with the recommendations of a 2010 review and 2012 follow-up review[10] of the Federal Networking and Information Technology R&D (NITRD) program by the President's Council of Advisors on Science and Technology (PCAST).

The overall HPC strategy and program portfolio receives guidance and input from the Advisory Committee for Cyberinfrastructure (ACCI) and its task forces as well as from the NSF cross-directorate CIF21 Council, which includes assistant directors (ADs) and office directors (ODs) from the various research directorates and offices, and the Cyberinfrastructure Coordination and Leadership Group.

PETASCALE COMPUTING – BLUE WATERS (formerly, HPC Track 1)

Description

The National Center for Supercomputing Applications (NCSA) at the University of Illinois at Urbana-Champaign (UIUC) is now providing computational resources for researchers to tackle much larger and more complex research challenges than previously possible. This was accomplished by acquiring, deploying, and operating a petascale leadership-class, high-performance system known as Blue Waters. Blue Waters is one of the most powerful supercomputers in the world, and is the fastest supercomputer on a university campus. It is important to note that this investment complements the DOE Office of Science's program on computing hardware, which provides sustained petascale performance. In contrast, Blue Waters provides peak petascale performance.

[9] www.nsf.gov/pubs/2012/nsf12051/nsf12051.pdf

[10] *Designing a Digital Future: Federally Funded Research and Development Networking and Information Technology,* President's Council of Advisors on Science and Technology, January 2013.

Blue Waters also complements the broad set of resources provided through the Innovative HPC program and eXtreme Digital (XD) environment. While Innovative HPC supports a portfolio of technically diverse systems capable of supporting hundreds to thousands of researchers over the course of a year, Blue Waters provides resources to focus on a small set of the largest and most computational-intense scientific advances demanding petascale capabilities. (For more information on Innovative HPC see below.) XD differs as well from Blue Waters in that XD delivers a broader set of capabilities to a much larger community. (For more information on XD, see the discussion on TeraGrid Phase III that is included in this appendix.)

The Blue Waters system was operational in December 2012, and the archival storage availability came online in March 2013. It is operated by NCSA and includes the Great Lakes Consortium for Petascale Computing (GLCPC) as a partner.

The Blue Waters project also includes education and outreach programs that target pre-college, undergraduate, graduate, and post-graduate students. A Virtual School of Computational Science and Engineering was established as part of the project. It created courses and certificate programs focusing on petascale computing and petascale-enabled science and engineering. The Blue Waters project has also sponsored workshops, conferences, summer schools, and seminars.

The Blue Waters project includes an annual series of workshops targeted at the developers of simulation packages and aspiring application developers. The project also includes two industrial partnership activities. The Industry Partners in Petascale Engagement (IPIPE) program provides industrial partners with a first look at the technological and scientific developments that flow from the petascale program. The Independent Software Vendor Application Scalability Forum promotes collaborations among consortium members, independent software vendors, and the industrial end-user community.

The broader impacts of this award include provisioning unique infrastructure for research and education; extensive efforts accelerating education and training in the use of high-performance computation in science; training in petascale computing techniques; promoting an exchange of information between academia and industry about the applications of petascale computing; and broadening participation in computational science through NCSA's Girls Engaged in Mathematics and Science (GEMS) program. The GEMS program is designed to encourage middle-school girls to consider mathematics- and science-oriented careers.

Current Status

In late September 2011, Cray was selected as the vendor for the Blue Waters project. Following system testing and acceptance in December 2012, and acceptance of the NCSA archival system in March 2013, the Blue Waters project entered a five-year operations phase. Support for the first six months of operations was provided in the acquisition and deployment award. Support for the remaining operational phase, from FY 2014 through mid-FY 2018, was awarded to UIUC in FY 2013.

The Blue Waters education and outreach projects are ongoing, with components on undergraduate education, graduate education, training workshops, and outreach. Annual “Petascale Workshops” provide scientists and engineers with the knowledge and expertise to develop applications for Blue Waters and other petascale computers. In addition, annual extreme scale workshops are held jointly with the Extreme Science and Engineering Discovery Environment (XSEDE) project. The Blue Waters team also hosts summer workshops and has created and offered courses through the Virtual School of Computational Science and Engineering mentioned above. Partnering with the Shodor Foundation, a nonprofit national resource for computational science education, the Blue Waters project has offered undergraduate course materials and internships. In 2014, Blue Waters Graduate Fellowships were announced for ten students from nine institutions in eight different states across the U.S.

Science and engineering research and education activities enabled by Blue Waters

Blue Waters is enabling investigators across the country to conduct innovative research demanding petascale capabilities. In particular, allocations of time on Blue Waters began in 2013 for approximately 30 teams, with a second round of awards to 14 teams made in 2014. These research teams were awarded time on Blue Waters through the Petascale Computing Resource Allocations (PRAC) process. Approximately 150 requests for usage were submitted across a wide spectrum of research areas. The research topics include: complex biological behavior in fluctuating environments; the electronic properties of strongly correlated systems; the properties of hydrogen and hydrogen-helium mixtures in astrophysically relevant conditions; the electronic and magnetic structures of transition metal compounds; the molecular dynamics responsible for the properties of liquid water; and the propagation of seismic energy through a detailed structural model of Southern California together with the predicting of ground motion and the modeling of the response of buildings and other structures. Other allocations address testing hypotheses about the role of cloud processes and ocean mesoscale eddy mixing in the dynamics of climate and improving climate models; the formation of the first galaxies; turbulent stellar hydrodynamics; binary black hole and neutron star systems as sources of gamma ray bursts; and other intense radiation phenomena, contagion, and particle physics.

Over 50 scientific papers were published each year in 2013 and 2014 based on research conducted using Blue Waters allocations. A new PRAC call was issued in November 2014, and it is anticipated that 15-20 additional awards will be made by the end of FY 2015. Furthermore, the project has issued calls for educational allocations directly involving students; including the Blue Waters undergraduate student internship program (21 students in 2014) and the Blue Waters Graduate Fellowship program (10 awards in 2014). After one year in service, Blue Waters has supported over 120 science projects (research, education, industry outreach, national, GLPCC and University) and 600 leading scientists.

Management and Oversight

NSF Structure: The project is overseen by CISE/ACI program staff and a grants officer from the Division of Grants and Agreements (DGA). These NSF staff members receive strategic advice from the CIF21 Council. Advice from the Office of General Counsel (OGC) is sought, as necessary.

External Structure: During the development and acquisition phase of this project, UIUC oversaw work by a number of sub-awardees, conducted software development, and assisted competitively selected research groups to prepare to use the Blue Waters system. The primary sub-awardee, Cray, is responsible for maintenance of the hardware, system software, and main program development tools. Other sub-awardees worked on extreme-scale parallel algorithm and method development, the engagement of applications groups, scalable performance tools, undergraduate training, and broadening the participation of underrepresented groups in high-performance computing. During the operational phase, the project team is advised by the Science and Engineering Team Advisory Committee (SETAC) whose make-up and roles were reviewed and approved by the external panel in July 2013. This Committee is composed of representatives from research teams with Blue Waters allocations, industry scientists pursuing petascale applications, and GLCPC.

Risks: The NSB will receive updates on any major change in risk assessment, which is reviewed annually by an external panel. Risks identified during the operational phase of the project include system security, power costs, and performance/reliability/usability due to large system scale.

Reviews: The project was initially selected through a competitive merit review process in 2007 and a subsequent renewal project that was reviewed and approved in 2013. An external panel of experts, selected by NSF, periodically reviews the progress of the project including project management, risk management, hardware and software performance, usability and reliability, and the provision of advanced user support to research groups receiving resource allocations on the Blue Waters system. One of the

important roles of this external review panel is to analyze the awardee's assessments of scientific merit and broader impact based on the use of the system for research and education. To date, these external reviews have been conducted in February 2008, April 2008, October 2008, April 2009, July 2009, December 2009, April 2010, September 2010, December 2010, February 2011, May 2011, September 2011, March 2012, August 2012, December 2012, July 2013, and December 2014.

INNOVATIVE HPC PROGRAM (formerly, HPC Track 2)

Description

Innovative HPC systems provide petascale peak performance. The key difference from the DOE Office of Science support for computing hardware is that each system is capable of supporting hundreds to thousands of researchers (over the course of a year) conducting leading-edge science and engineering. The portfolio of systems supported by the Innovative HPC program is intended to be technically diverse, reflecting changing and growing use of computation in both the research and education process. NSF's support complements and extends campus and regional research cyberinfrastructures. All Innovative HPC awards are made in the context of the XD program (described below).

There is a direct relationship between the Innovative HPC and XD programs. Several systems are currently serving as allocable resources within XD. Innovative HPC awards are generally made as two parts: an acquisition component with associated funding, and an operations and maintenance component with associated funding. Some Innovative HPC awards do not separate these components because of the experimental nature of the systems. When an award is made, funding is provided to the institution, which issues sub-awards to vendors for acquisitions as necessary. Once the system has passed the acceptance process, vendors receive final payment for the system. After the system has been fully tested, it becomes an XD resource and the institution becomes an XD resource provider. At this point the award funding may be used for operations and maintenance of the system.

Beginning with the FY 2011 solicitation, *High Performance System Acquisition: Enhancing the Petascale Computing Environment for Science and Engineering*, a more sustained approach to the largest HPC services was initiated. This solicitation was based on feedback from the scientific and engineering community, providing a longer time horizon for funding HPC providers in recognition of the value and time required for building and retaining staff skilled in interdisciplinary computational science. Thus, an eight- to ten-year award horizon is envisioned for a core HPC provider. This timeline begins with an acquisition award, which allows for the possibility of a renewal acquisition award four years after the original award. In addition to the acquisition awards, accompanying operations and maintenance (O&M) awards are planned.

Current Status

Machines that have been operational in the Innovative HPC program include Stampede, Blacklight, FutureGrid, Gordon, Keeneland, Kraken, Lonestar, Longhorn, and Trestles. Blacklight, FutureGrid, Kraken and Longhorn are no longer part of the current NSF HPC portfolio, although Blacklight is still supported by the Data cluster in CISE/ACI. NSF support for Gordon, Keeneland, and Trestles is scheduled to end in FY 2016.

Two new resources are now being deployed, resulting from awards made following a FY 2013 solicitation. Compared to earlier solicitations, the FY 2013 solicitation was designed to broaden the spectrum of the program by exploring new and creative approaches to delivering innovative computational resources to an increasingly diverse community and portfolio of scientific research and education projects. The goal is to include new communities with needs that are different than the more

traditional HPC users, but which would benefit from advanced computational capabilities at the national level.

The resources were funded jointly by CISE/ACI's HPC and Data programs. The first award, Wrangler, is scheduled to come online in FY 2015 at the University of Texas at Austin, and is supported by the CISE/ACI Data cluster. Upon its deployment, Wrangler will be the most powerful data analysis system allocated in XD, with 10 petabytes (PB) of replicated, secure, high performance data storage. It will consist of 3,000 embedded processing cores for data analysis; 120 Intel Haswell-based servers for data access and embedded analytics; and a large-scale flash storage tier for analytics, with bandwidth of one terabyte per second (TB/s) and 275 million Input/Output Operations Per Second (IOPS). The system will provide flexible support for a wide range of software stacks, including Hadoop and relational data, as well as integrate with Globus Online services for rapid and reliable data transfer and sharing. Support for ongoing Wrangler operations and maintenance, starting in FY 2015 and continuing through FY 2019, is provided to the University of Texas at Austin at approximately 20 percent of initial acquisition cost per annum level, consistent with the identified level provided in the FY 2013 solicitation.

The second award, Comet, also scheduled to come online in FY 2015 at the University of California at San Diego, is supported by the CISE/ACI's HPC program. It is designed to be part of an emerging cyberinfrastructure for the "long tail of science," which encompasses the idea that a large number of modestly sized computationally-based research projects still represent a tremendous amount of research and scientific impact. Notably, as a resource that is responsive to the "long tail of science," Comet is particularly well-suited for science gateway use. Its heterogeneous configuration will support not only complex simulations, but also advanced analytics and visualization of output.

A new solicitation was issued in FY 2014 (*High Performance Computing System Acquisition: Continuing the Building of a More Inclusive Computing Environment for Science and Engineering*) to continue the intent of the FY 2013 solicitation and add complementary computational resources to the NSF portfolio. This solicitation resulted in two awards: the "Bridges" system to be deployed at the Pittsburgh Supercomputing Center and "Jetstream" at Indiana University. Both systems are scheduled to be deployed in FY 2016.

Bridges will provide an innovative and groundbreaking HPC and data-analytic system that will integrate advanced memory technologies to empower new communities, bring desktop convenience to high performance computing, connect to campuses, and intuitively integrate data-intensive workflows to increase the scientific output of a large community of scientific and engineering researchers who have not traditionally used HPC resources by lowering the barrier of entry to HPC. Bridges will extend HPC's impact to minority-serving institutions and EPSCoR states, raising the level of computational awareness at four-year colleges, and promote computational thinking in high-schools.

Jetstream will be a new type of data analysis and computational resource for the open science and engineering research community that will be used interactively to conduct research anytime, anywhere. It complements the current NSF-funded computational resources portfolio by bringing online a cloud-based system incorporating the best elements of commercial cloud computing resources with some of the best software in existence for solving important scientific problems. Jetstream enables new modes of sharing computations and data, allowing for increased scientific reproducibility and enabling many US researchers and engineers to make new discoveries that are important to understanding the world around us, improving the quality of life of American citizens, and promoting America's competitive standing.

For both Bridges and Jetstream, support for ongoing operations and maintenance, starting in FY 2015 and continuing through FY 2019, is provided at approximately 20 percent of initial acquisition costs per annum, consistent with the identified level provided in the FY 2014 solicitation.

These additions replace several of the resources mentioned above that will no longer be supported, primarily Trestles and Gordon. However, they also represent additional capabilities that are intended to appeal to the larger and increasingly diverse demand for national-scale resources.

The Stampede project at the University of Texas at Austin delivered a new system for allocation of NSF XD cyberinfrastructure services in January 2013, and is scheduled to operate until January 2017. The resource and accompanying services target science and engineering researchers using both advanced computational methods and emerging data-intensive approaches. The system has boosted XD resources to nearly twice their previous capacity, and has provided researchers with early access to Intel Many Integrated Core (MIC) processors, which were accepted in August 2013.

Science and engineering research and education activities enabled by Innovative HPC

- The complete spectrum of scientific research can leverage Innovative HPC resources. This includes climate and weather modeling, economics, cosmology and astrophysics, geosciences, physics, chemistry, biology and medicine, earthquake engineering, and mechanical engineering.
- Innovative HPC is enabling world-leading transformative advances in science and engineering research, in the integration of research and education, and in broadening participation in science and engineering by underrepresented groups. These advances are enabled by providing researchers and educators with usable access to computational resources beyond those typically available on most campuses, together with the interfaces, consulting support, and training necessary to facilitate their use.
- Through the unifying XD framework and services, Innovative HPC enables researchers to manipulate extremely large amounts of digital information from simulation, sensors, and experiments, and add needed capabilities in remote visualization, an increasingly important analysis tool for modern science and engineering.
- Outreach and training critical to reducing the barriers to the use of HPC systems by the research and education community will be provided by engaging research universities and foundations. Innovative HPC incorporates new computational technologies and new approaches to software and data management, together with the expertise to enable researchers and students to complement theory and experiment with an equal emphasis in computation.

Management and Oversight

NSF Structure: CISE/ACI's program directors provide direct oversight during both the acquisition and operations phase. Formal reporting consists of quarterly and annual reports, which are reviewed by the program directors. The program directors also hold bi-weekly teleconferences with the awardees.

External Structure: Each Innovative HPC award is managed under a cooperative agreement. Each awardee is responsible for the satisfactory completion of milestones in order for the spending authorization to be raised. Progress is evaluated by annual reviews and the NSF program directors.

Each project has a detailed management plan in place. Each cooperative agreement includes the management structure, milestones, spending authorization levels, and review schedule.

Risks: Any activity of this nature, and at this scale, comes with a certain element of risk. The review process, conducted prior to award, analyzes the risks as presented in the proposal and identifies any additional risk that should be considered. The awards are experimental in nature; therefore, they encompass high-risk, high-reward scenarios. The award process requires that risks be identified and analyzed, and that a mitigation plan be created and followed. One of the activities of the periodic NSF external reviews, conducted by an external panel of experts, is to revisit and assess the risk situation and

make recommendations as deemed necessary. Risks that are no longer applicable are retired. New risks may be added, or degree of risk promoted or demoted as necessary, all of which is documented in a risk register. Typically, project risks are substantially reduced subsequent to deployment. Thus, pacing of acquisitions and deployments allows balance in overall portfolio risk for Innovative HPC.

Reviews: Semi-annual reviews are typically performed during the acquisition phase. Annual reviews, conducted by an external panel of expert reviewers, are performed during the operational phase of each project. The reviews are managed by NSF program directors. The reviewers' backgrounds include scientific research, project management, large-scale systems acquisitions and operations, and a familiarity with projects funded by NSF, as well as other federal agencies. To the extent possible, continuity through this series of reviews is provided by using the same set of reviewers.

EXTREME DIGITAL (XD) (formerly, TERAGRID PHASE III)

Description

Extreme Digital (XD), successor to the TeraGrid program, creates and maintains an advanced, nationally distributed, open cyberinfrastructure comprised of shared user and management services, supercomputing, storage, analysis, visualization systems, data services, and science gateways connected by high-bandwidth networks, integrated by coordinated policies and operations, and supported by computing and technology experts.

XD enables and supports leading-edge scientific discovery and promotes science and technology education. The program encourages innovation in the design and implementation of an effective, efficient, increasingly virtualized approach to the provision of high-end digital services, known as extreme digital services, while ensuring that the infrastructure continues to deliver high-quality access for the many researchers and educators that use it in their work.

XD shared services consist of several interrelated parts: Technology Audit Service (TAS); Technology Insertion Service (TIS); Coordination and Management Service (CMS); Extended Collaborative Support Service (ECSS; formerly Advanced User Support Service); and Training, Education and Outreach Service (TEOS). The last three elements constitute the XSEDE project; the other elements are implemented via separate awards. These elements are designed and implemented in a way that is consistent with sound system engineering principles, clearly tied to the user requirements of the science and engineering research community using a flexible methodology that permits the architecture to evolve in response to changing user needs and presents the individual user with a common user environment regardless of where the resources or user is located

Current Status

Three awards are currently active within the XD program. The two smaller awards, TAS and TIS, were made in FY 2010 to the University at Buffalo, The State University of New York, and to UIUC, respectively. The largest award, comprising CMS, ECSS and TEOS, and known as the XSEDE project, was made to UIUC in July 2011 for advanced user support, education and outreach, and management services of XD. The four additional major partners in XSEDE are the University of Texas at Austin (Texas Advanced Computer Center), the University of Pittsburgh (Pittsburgh Supercomputer Center), the University of Tennessee at Knoxville (National Center for Computational Science), and the University of California at San Diego (San Diego Supercomputer Center). XSEDE has had three annual reviews at NSF in June 2012, June 2013, and September 2014.

Science and engineering research and education activities enabled by XD

- XD services enable transformative advances in science and engineering research, in the integration of research and education, and in broadening participation in science and engineering to under-represented groups. This is accomplished by providing researchers and educators with coherent and highly usable access to extreme-scale digital resources beyond those typically available on most campuses, together with the interfaces, consulting, advanced user support, and training necessary to facilitate their use.
- XD provides high-performance computing services; enables researchers to manipulate extremely large amounts of digital information from simulations, sensors, and experiments; and adds needed capabilities in remote visualization, an increasingly important analysis tool for modern science and engineering.
- XD's XSEDE project is developing tools and services that not only link users to national facilities, but also enable scientific collaborations of geographically distributed teams. In doing so, it facilitates access to digital resources and experimental testbeds within and across university campuses, as well as government laboratories.
- The XSEDE project includes outreach and training critical to reducing the barriers to the use of advanced digital systems by the research and education communities. The project incorporates new ideas and technologies to enable researchers and students to move transparently between local and national resources, substantially lowering the barriers to effective use of cyberinfrastructure and promoting enhanced productivity.

Management and Oversight

NSF Structure: CISE/ACI program directors oversee the TAS, TIS, and XSEDE projects. XSEDE has an external advisory board, a user board, and a service provider forum to ensure that all stakeholders can provide project input. CISE/ACI oversight of the XSEDE project includes participation in weekly teleconferences with senior XSEDE personnel and in the quarterly project-wide staff meetings. Formal reporting consists of quarterly and annual reports, which are reviewed by the program directors.

External Structure: Each XD award is managed under a cooperative agreement. Each awardee is responsible for the satisfactory completion of milestones prior to processing of grant increments. Each project has a detailed management plan in place. Each cooperative agreement includes the management structure, milestones, spending levels over time, and review schedule.

Risk: While XD is operational in nature, the virtual organizations of the XSEDE project and the services of all XD projects are innovative and thus bear inherent risks. The projects maintain risk registers that are reviewed periodically by external panels and by the cognizant program directors. Identified risks and planned actions are reported to, and reviewed with, the program directors.

Reviews: Annual reviews (for XSEDE) and mid-project reviews (for TIS and TAS) are conducted by an external panel of expert reviewers. The reviews are managed by the program directors. The reviewers' backgrounds include scientific research, project management, operations of HPC centers, and familiarity with projects funded by NSF, as well as other federal agencies. To strike a balance between continuity and broad community engagement, approximately half of the annual review panel members have served in this role previously while the other half are new members.