SCIENCE, ENGINEERING AND EDUCATION FOR SUSTAINABILITY (SEES)

Goal
Advance climate and energy science, engineering, and education to inform the societal actions needed for environmental and economic sustainability and sustainable human well-being.

Description and Rationale
SEES is designed to foster insights about the environment-energy-society nexus that will increase the effectiveness of our energy and management policies in adapting to, and mitigating the impacts of, environmental and climate change. SEES research will improve our capabilities for rapid response to extreme events, such as power grid disruption, floods, or extreme weather.

In response to numerous major community reports, including the National Science Board's *Building a Sustainable Energy Future* (2009), NSF developed the Science, Engineering, and Education for Sustainability (SEES) portfolio in FY 2010, by drawing the programs that address sustainability into a common framework to optimize investments and outcomes. The shape of the portfolio was influenced by reports from many disciplines, such as *The Mathematics of Climate Change: A New Discipline for an Uncertain Century* (Mathematical Sciences Research Institute, 2007), and various assessments such as the United States Climate Change Science Program report, the *Effects of Climate Change on Energy Production and Use in the United States* (2008). Initial efforts focused on coordinating a suite of research and education programs at the intersection of climate and environment, with specific attention to human behavior. NSF released solicitations that aligned with and expanded key aspects of the existing SEES portfolio. In FY 2010, these solicitations (Water Sustainability and Climate; Dimensions of Biodiversity; Ocean Acidification; Regional and Decadal Earth System Modeling; and the Climate Change Education Program) resulted in 70 awards totaling approximately $66.0 million.

Beginning in FY 2012, NSF will expand the SEES portfolio (+$337.45 million, to a total of $998.19 million) through significant investments that 1) continue the integration, responsiveness, and effectiveness of ongoing programs; 2) emphasize research and education on Sustainable Energy Pathways (SEP); 3) institute a formal program of Postdoctoral Fellowships in Sustainable Solutions; 4) initiate a program of interdisciplinary Sustainability Research Networks (SRNs) linking existing and new nodes; and 5) include international connections through targeted awards in the Partnerships for International Research and Education (PIRE) program. These SEES plans align with key national and NSF priorities to stimulate the discovery and innovation needed to address the challenges of creating sustainable energy solutions and building human capacities to imagine, design, and implement them.

SEES themes will also be reflected in other major FY 2012 investments. These include: 1) the new $20.0 million Widening Implementation and Demonstration of Evidence-based Reforms (WIDER) program in the Directorate for Education and Human Resources, which aims to advance large-scale improvements to undergraduate STEM educational practices; and 2) the new $12.3 million Integrated NSF Support Promoting Interdisciplinary Research and Education (INSPIRE) program under the Office of Integrative Activities, which has the dual objectives of fostering research in multiple disciplines and lowering the disciplinary barriers that exist within NSF and in the research community.

Integrated Science and Engineering Research on Environmental, Economic and Energy Systems (+$47.75 million in FY 2012): NSF has broad and long-standing investments in environment, energy, climate, social and behavioral sciences, education and workforce development, mathematics, and many other areas of fundamental research and education that provide a foundation for the development of innovative solutions to pressing problems in sustainability. Research in such areas as complex environmental and climate-system responses and pathways will continue to be supported and emphasized across NSF and will be matched by increased emphasis on activities focused on sustainable and clean

energy technologies. These solutions must simultaneously take into account social, environmental, and economic sustainability, through deep understanding of how these systems interact with one another.

NSF's unique mandate to support all areas of science, engineering, and science education allows it, through SEES, to address research aimed at tackling the full range of complex system level problems. SEES research will include investigation of the fundamental role of social, economic, and political systems as well as the conceptual, theoretical, empirical, and computational challenges needed to further develop the basic science, engineering, education, and policy knowledge base required for planning at both individual and systems levels.

The NSB report outlined a range of needed research investments in the area of sustainable energy, including: novel energy storage schemas; ecosystem impacts of energy technologies; improving the efficiency and yield of established and emerging energy systems; and the development of clean energy sources, such as biofuels and ocean/kinetic power. In response, SEES will investigate energy-intelligent computational performance in computer and network systems, as well as use of information technology in smart sensing systems that have the potential to save energy. Energy efficiency and renewable alternatives to fossil fuels and raw materials in manufacturing processes will be stressed, as will research on economical alternatives to traditional chemical products and practices.

SEES research will address some key scientific uncertainties identified in the Intergovernmental Panel on Climate Change (IPCC) report. These include: interactions among the climate, human, and natural systems; feedbacks in the climate, particularly carbon cycles; impacts of ice sheets dynamics on climate change and sea level rise; regional climate change and causes; the difference between low probability/high impact events and high probability/low impact events on risk-based approaches to decision making; interactions between socio-economic factors and the evolution and utilization of adaptive and mitigating strategies; barriers, limits and costs of adaptation; and effects of lifestyle and behavioral changes on energy consumption and climate.

SEES will have an enhanced focus on the dramatic stresses faced by the linked coasts and oceans and the Arctic region. Productive and fragile, these ecosystems and coastal communities continue to feel the sharp impact of occasional disasters, such as oil spills, superimposed on the gradual but inexorable pressures of human use, warming temperature, and rising sea level. Data on climate, energy, and the environment will also be integrated with information on human demographics and other trends.

In addition to advances in research, the FY 2012 awards will include activities that help prepare an informed, solutions-oriented citizenry and future workforce to address the complex problems and decisions associated with sustainability. Experiences for undergraduate, doctoral, and postdoctoral students will complement experiences currently supported by the Climate Change Education program, which includes projects on public engagement with science.

Sustainable Energy Pathways (SEP) (+$178.20 million in FY 2012): The creation of a secure and prosperous future depends on progress toward reliable energy resources that will not degrade essential ecosystems and environmental services, nor lead to unacceptable social or economic consequences. One of NSF's strengths is the ability to mobilize the social, behavioral, and economic science research community to work in close collaboration with natural scientists and engineers to provide a comprehensive and integrated approach to solving questions of sustainability.

Potential areas that may benefit from this integrated approach include: technological and societal hurdles and options for a hydrogen economy; development and acceptance of new materials for higher-efficiency/lower-cost energy production, novel battery components, and energy transmission technologies; optimization of energy usage through new algorithms and intelligent decision-making for

computational and data-intensive systems; controls and limits on primary productivity and land use; access and optimization challenges for renewable energy sources, such as solar, wind, tidal, geothermal, and biomass; energy storage technologies to overcome the intermittency of energy generation from certain sources and capacitors; and the human dimensions of decision-making with respect to a low carbon energy future, and associated assessments of economic and environmental risks and impacts for each technology solution.

Specific SEP goals are to:

- Create the fundamental knowledge base necessary to characterize and understand existing energy systems and their limitations, and to imagine, invent, and deploy clean and renewable energy systems, as appropriate and in partnership with the Department of Energy (DOE) and other agencies;
- Explore innovative and sustainable alternative energy sources and technologies;
- Investigate novel pathways for human energy futures based on a comprehensive understanding of risks and stressors associated with new energy approaches and their environmental responses, including biological, hydrological, and societal aspects;
- Develop human capital to address the interdisciplinary challenge of building a sustainable energy future; and
- Foster public engagement with issues of energy sustainability science and engineering.

Postdoctoral Fellowships in Sustainable Solutions (+$11.50 million in FY 2012): A postdoctoral fellowships program will continue in FY 2012. The program's emphasis is on gaining experiences that build bridges between academic inquiry, economic growth, and societal needs. These may range from research expertise in energy technology development to investigation of how to facilitate the public's adaptation of those technologies. Sustainability issues require inherently interdisciplinary research and education efforts–often at the intersection of the environmental sciences, engineering, and the social and behavioral sciences—and these efforts often do not fit neatly into traditional academic structures. Because near term capacity needs are critical, it is necessary to reduce institutional barriers in order to enable existing faculty members, as well as those who are just entering the postgraduate workforce, to effectively contribute to solving complex sustainability-related problems. While eligibility for these fellowships is open to recent and early doctoral scientists and mid-career faculty, applicants are required to gain expertise in a discipline different from the one in which they have been educated or working. The fellow is also expected to develop a partnership activity that would broaden the impact and/or scope of sustainability efforts, such as a connection with: an SRN or industry; a national laboratory; an NSF-supported center or facility; a professional society; a state, regional, or local resource management agency; an education project that focuses on public engagement and broadening participation; or another appropriate entity.

Sustainability Research Networks (SRN) (+$85.0 million in FY 2012): A primary way NSF will address the SEES goals is through Sustainability Research Networks (SRNs), which cross the boundaries of all scientific disciplines. Through the existing Research Coordination Networks program and other NSF programs encouraging collaborations, investigators have begun to build teams and explore fundamental theoretical issues and empirical questions, such as how our nation can move toward improved predictions, technologies, policies and practices to achieve sustainability and how we can harness clean and renewable sources of energy to build healthy environments and conserve biodiversity on Earth, while ultimately enhancing economic vigor and human well-being.

In FY 2012, best practices from existing NSF activities will guide expansion of each network's reach and integrate the major themes of energy, environment, and the economy. All SRNs will be required to design educational and information exchange systems to engage the general public and policymakers in understanding sustainability issues and to help scientists understand societal needs. These networks will

tap highly talented individuals from both the U.S. and other countries who represent a spectrum of disciplines, perspectives, and research methods. These scientists, unconstrained by institutional boundaries, will work together to develop and deploy cyberinfrastructure to convey and meld disparate sources of data. These networks will connect with existing centers of research excellence, such as relevant Science and Technology Centers (STCs) and Engineering Research Centers (ERCs), which investigate sustainability science and engineering topics such as predictive modeling and decision-making under uncertainty. A fully-developed network would include network-level research, cyberinfrastructure for data management and modeling, student support, workforce training, community engagement in the network's thematic areas, and evaluation and assessment activities. It is important to note that not all activities in the SRN networks will be supported solely by NSF; for example, DOE Innovation Hubs, focused on solar energy and energy storage, which are basic research topics of interest to both agencies, might be associated with SRN networks.

Partnerships for International Research and Education (PIRE) (+$15.0 million in FY 2012): Many of the intellectual and practical SEES challenges are global in scope and require a comparative understanding of geographic, ecological or cultural variability. International activities in sustainability will seed new paradigms for the cross-fertilization of ideas based on region-specific resources, and will provide access to international expertise, facilities, and data. The PIRE competition will focus on sustainability research—integrating topics such as clean and renewable energy, environmental resilience, and regional economies—with other countries by facilitating the exchange of ideas, materials, instrumentation, researchers, and students. Many of these teams will be linked with SRNs to enhance their global impact.

Other Partnerships: A hallmark of SEES has been, and will continue to be, formation of partnerships with other agencies and appropriate entities. The United States Department of Agriculture (USDA) and DOE have participated in SEES programs. Discussions with USDA, DOE, the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), and the United States Geological Survey (USGS) indicate considerable interest in building joint programs and sharing infrastructure. Industrial partnerships will help define and discover the basic science needed to build a sustainable industrial base. Included in these efforts will be activities aimed at bolstering industry/university interactions, such as forums and networks that connect fundamental research developments with regional and national innovation ecosystems, and related activities through the Engineering Research Centers (ERCs), Science and Technology Centers (STCs), Industry/University Cooperative Research Centers (I/UCRC) program. Research funding agencies from a number of other countries, including the European Union, have expressed considerable interest in offering parallel solicitations on sustainability topics.

Management, Assessment, and Funding

Activities in FY 2012 and beyond will include enhancing ongoing programs, deepening integration among programs, and issuing new SEES solicitations. A roadmap of detailed plans has been developed to guide program development, management, and evaluation. The portfolio of investments will continue to be led by a senior NSF leadership team and coordinated by an implementation group of senior managers. Working groups of program officers will manage specific solicitations. The overall program will be reviewed by several NSF Committees of Visitors, with particular attention paid by the Advisory Committee for Environmental Research and Education. The impact of the networks' research results and their dissemination will be measured by program review methods appropriate to each program. Evaluation tools will include bibliometric analysis of research publications, STAR Metrics to assess human capital development, and wiki crowd sourcing to monitor biodiversity milestones. Evaluation of the postdoctoral fellowship program, for example, will assess the extent to which interdisciplinary experiences and direct connections with practitioners help meet the goal of identifying research needs and disseminating solutions. By 2015, the impact of the SEES program will be measured against its goals to:

increase the knowledge base available to scientists and decision-makers; accelerate identification and deployment of technologies to address sustainability issues; and create a robust cadre of early career sustainability scientists and engineers.

SEES Portfolio Funding

(Dollars in Millions)

	FY 2010 Enacted/ Annualized FY 2011 CR	FY 2012 Request Level
Biological Sciences	$121.00	$146.00
Computer and Information Science and Engineering	17.00	46.36
Engineering	108.20	162.00
Geosciences	195.50	282.70
Mathematical and Physical Sciences	87.00	160.00
Social, Behavioral and Economic Sciences	20.78	56.98
Office of Cyberinfrastructure	5.50	5.00
Office of International Science and Engineering	2.50	17.00
Office of Polar Programs	65.26	83.65
Office of Integrative Activities	26.50	26.50
Subtotal, Research and Releated Activities	$649.24	$986.19
Education and Human Resources	11.50	12.00
Total, SEES	**$660.74**	**$998.19**

Totals may not add due to rounding.