NSF Sensational 60

Celebrating 60 Years of Discovery

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Introduction

The National Science Foundation (NSF) is an independent federal agency that supports fundamental research and education across all fields of science and engineering. Congress passed legislation creating the NSF in 1950 and President Harry S. Truman signed that legislation on May 10, 1950, creating a government agency that funds research in the basic sciences, engineering, mathematics and technology. NSF is the federal agency responsible for nonmedical research in all fields of science, engineering, education and technology.

NSF funding is approved through the federal budget process. In fiscal year (FY) 2010, its budget is about $6.9 billion. NSF has an independent governing body called the National Science Board (NSB) that oversees and helps direct NSF programs and activities.

NSF funds reach all 50 states through grants to nearly 2,000 universities and institutions. NSF is the funding source for approximately 20 percent of all federally supported basic research conducted by America's colleges and universities. Each year, NSF receives over 45,000 competitive requests for funding, and makes over 11,500 new funding awards. NSF also awards over $400 million in professional and service contracts yearly.

NSF has a total workforce of about 1,700 at its Arlington, Va., headquarters, including approximately 1,200 career employees, 150 scientists from research institutions on temporary duty, 200 contract workers and the staff of the NSB office and the Office of the Inspector General. However, more than 200,000 people, including researchers, graduate students and teachers, are involved in NSF programs and activities nationwide.

NSF is divided into the following seven directorates that support science and engineering research and education: Biological Sciences (BIO), Computer and Information Science and Engineering (CISE), Education and Human Resources (EHR), Engineering (ENG), Geosciences (GEO), Mathematics and Physical Sciences (MPS) and Social, Behavioral and Economic Sciences (SBE). Some of the offices within NSF's Office of the Director also support research and researchers. These offices include the Office of Polar Programs (OPP), which funds and coordinates all research efforts in the Arctic and Antarctic; the Office of Integrative Activities; the Office of International Science and Engineering and the Office of Cyberinfrastructure.

Sensational 60

During the past 60 years, we have seen incredible developments in science and engineering. NSF has played a role in that progress. As we celebrate the National Science Foundation (NSF)'s 60th anniversary, we can point with quiet pride to immeasurable ways work supported by NSF has served our society in practical, beneficial ways.

Within the section that follows are 60 discoveries or advances that NSF believes have had a large impact or influence on every American's life. We call this list the "Sensational 60", in honor of the National Science Foundation 60th anniversary.

Just as the path to discovery is seldom a straight line, so too is the process of selecting such a list. As in scientific research, the selection process involved trial and error and strong doses of patience and vision. All items in the Sensational 60 are listed alphabetically, and listing here does not imply any ranking of one item's importance over another.

NSF invites you to learn more about our leadership in scientific discoveries and the development of new technologies. We look forward to the next 60 years of discoveries and advances.

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1945 Vannevar Bush's "Science—The Endless Frontier" calls for the establishment of a National Research Foundation.

1950 On May 10, President Harry S. Truman signs Public Law 507 creating the National Science Foundation. The act provides for a National Science Board of 24 part-time members and a director as chief executive officer, all nominated by the President and confirmed by the Senate.

1951 NSF's initial appropriation is $225,000.

1952 Requesting from the Congress a first real budget of $33.5 million, NSF receives only $3.5 million; ninety-seven research grants are awarded.

1953 NSF's appropriation is $4.7 million; 173 research grants awarded.

1955 NSF moves toward funding "big science," which will eventually take a sizable portion of the foundation's budget. The mid-1950s see the growth of new centers for radio and optical astronomy and for atmospheric sciences.

Credit: Gemini Observatory

1957-58 The Soviet Union orbits *Sputnik* I on Oct. 5, 1957. It dramatically underscores in America the need for improving science education and basic research—deficiencies already known to the scientific community. In the year before *Sputnik*, the foundation's appropriation was $40 million. The year after *Sputnik*, it more than triples to $136 million.

1960 Emphasis on international scientific and technological competition further accelerates NSF growth. To build university infrastructure, the foundation starts the Institutional Support Program—the single largest beneficiary of NSF budget growth in the 1960s. NSF's appropriation is $154.8 million; 2,000 grants are awarded.

1966-68 NSF's budget reaches real-dollar peaks not attained again until the 1980s. The foundation's appropriation for both 1966 and 1967 is $480 million; education budget is 25 percent of NSF total.

1968 A major amendment to the NSF act expands the foundation's explicit responsibilities to include support for applied research and the social sciences; NSF's appropriation is $495 million.

1969 NSF takes a budget cut of nearly 20 percent from a spending-conscious Administration and Congress. The Mansfield Amendment limits the Department of Defense to mission-related basic research, placing additional responsibilities for support of basic research on NSF.

1971 A major new program is started—Research Applied to National Needs (RANN)—that focuses on research support of engineering, applied and environmental science.

1972 RANN growth, combined with transfers of basic research projects from the Department of Defense, creates an increase in the NSF budget; the Materials Research Laboratories Program is received from the Army; U.S. Antarctic Program operations budget is transferred from the Navy.

1973 Nixon Administration abolishes White House Office of Science and Technology; NSF Director H. Guyford Stever assumes new responsibility as science advisor.

1974 Research budget surpasses 80 percent of NSF's total annual budget and has remained above that level ever since. NSF receives 13,000 proposals and makes 6,400 awards. Institutional Support Program closes out; the Foundation expends nearly $2 billion over 15 years.

1975 Internal and external scrutiny of NSF's merit review process results in changes that open, clarify and codify its operation.

1976 Congress establishes the Office of Science and Technology Policy in the White House, terminating the dual role of the NSF director.

1977 RANN is phased out; programs go to other agencies and/or are incorporated into NSF research directorates.

1981 Engineering is elevated to separate NSF directorate; Directorate for Science Education is renamed the Directorate for Science and Engineering Education.

1982 First budget of the Reagan Administration dramatically reduces NSF budget for Science and Engineering Education.

1983 Major increase in research budget is proposed as the nation recognizes the importance of research in science and technology as well as education. A separate appropriation is established for the U.S. Antarctic Program. NSF receives more than 27,000 proposals—over 12,000 are awarded grants.

Credit: Jonathan Berry, National Science Foundation

1984 Advanced Scientific Computing Centers are established; first awards made in the Presidential Young Investigators Program.

1985 First awards made to new Engineering Research Centers.

1986 Various agency computer programs are organized under the new Directorate for Computer and Information Science and Engineering. Proposals received climbed to over 30,000, with awards topping 13,000.

1987 Office of Science and Technology Centers Development is established.

1988 Reagan Administration proposes five-year doubling of NSF budget.

1990 NSF's appropriation passes $2 billion for the first time; Science and Engineering Education budget doubles over the past three years.

1991 The new Directorate for Social, Behavioral and Economic Sciences is established.

1992 National Science Board establishes a Special Commission on the Future of NSF to examine how it can best serve the nation in the years ahead. The commission recommends that a new vision of the role of science and engineering in society be part of the national agenda for change.

1994 Fastlane project is launched, with the goal of automating and streamlining all business interactions between NSF and its external customers via the Internet. It is the first of its kind to automate interaction with the research and education communities.

1995 The first publication of NSF's Strategic Plan, *NSF in a Changing World* is released. It outlines the vision, goals and strategies for leadership and stewardship in scientific and engineering research and education.

1997 National Science Board approves new merit review criteria to evaluate proposals submitted to NSF. The new criteria mark the first change since 1981.

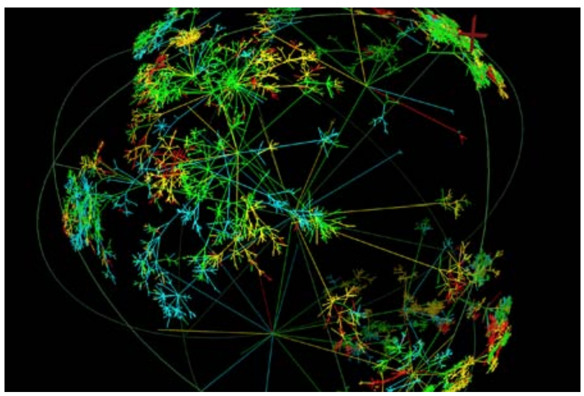
1999 NSF funding reaches a level of nearly $4 billion.

2000 The Clinton Administration proposes a $675 million increase to the NSF budget. This is double the largest increase ever proposed.

2003 NSF's appropriation exceeds $5 billion.

2004 Almost 44,000 proposals are submitted—a new high; less than one in four are funded.

2005 The Office of Cyberinfrastructure is established.



Credit: © 2002 The Regents of the University of California

2007-08 NSF leads U.S. participation in 4th International Polar Year.

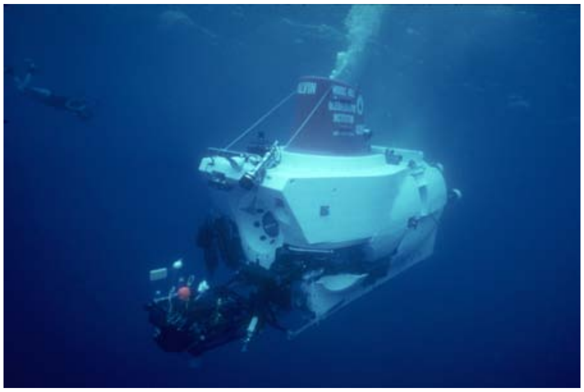
Credit: Christine Hush, National Science Foundation

2009 The American Recovery and Reinvestment Act provides $3 billion to NSF in addition to over $6 billion included in the appropriation.

2010 The Obama Administration budget request for NSF is over $7 billion.

1. Alvin: Deep-sea Explorer

Alvin, a deep-sea research vessel, and the world's oldest research submersible, can carry two scientists and a pilot as deep as 4,500 meters for dives that can last up to 10 hours. In 1973, NSF assumed responsibility for the contract originally managed by the Navy to support the Woods Hole Oceanographic Institution operation of *Alvin*.



Credit: Courtesy Woods Hole Oceanographic Institution

Since then, *Alvin* has been used in many scientific expeditions including: Project FAMOUS (French-American Mid-Ocean Undersea Study), which was the first comprehensive use of a manned submersible in a major scientific program, and confirmed the theory of plate tectonics and continental drift in 1974; the discovery of hydrothermal vents in 1977 and black smoker sulfide chimneys in 1979; and the exploration of the wreck of RMS *Titanic* in 1986. Research in *Alvin* has also been essential in demonstrating the great diversity of life in the deep-sea.

With funding from NSF, researchers designed a new, more capable HOV (Human Occupied Vehicle) as part of a collection of ocean research tools that include remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs). The improved speed and maneuverability of these new tools will make underwater exploration more efficient.

2. Cataloging the Sign

For more than half of the 20th century, sign language was regarded by experts and the general public alike as some sort of inferior gestural system, more of a handicap than a help to the deaf who used it. The reigning establishment in deaf education favored an "oralist" approach, which emphasized teaching students to read lips and pronounce words without the use of signing. That changed when William Stokoe, a young English professor at Gallaudet College (now Gallaudet University), the leading higher-education institution for the deaf, who had studied linguistics and American Sign Language (ASL), discovered that ASL was as complex and highly structured as spoken languages are.

Credit: © 2010 JupiterImages Corporation

With an NSF grant, Stokoe and two colleagues at Gallaudet published the *Dictionary of American Sign Language on Linguistic Principles* (1965), which in turn drew the attention of the linguistic community to ASL. Further research by scientists, primarily supported by NSF, led to an understanding that ASL has all of the fundamental formal properties of a spoken language, including a visual counterpart to the phonology (sound structure). This discovery opened up a whole new dimension in linguistic study and revolutionized deaf education in the United States.

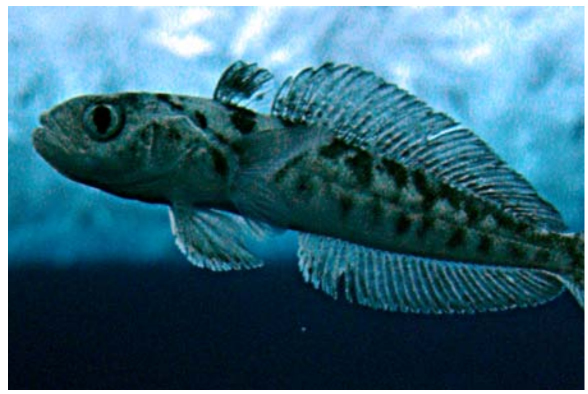
NSF continues to support research on ASL. At the same time, while recognizing that sign languages differ around the world, NSF has expanded its purview to include important cross-linguistic work, thus enriching our knowledge of sign languages and languages in general.

3. Antifreeze Proteins: Why You'll Only Find Frozen Fish in the Freezer

In the late 1960s, NSF-funded research discovered that antifreeze glycoproteins in the blood of Antarctic notothenioid fish protect them from the dangers of freezing in subzero temperatures. The compounds inhibit the growth of ice crystals, preventing damage to cells and tissues. After the discovery in Antarctic fish, researchers found similar compounds in other cold-water fish, insects, plants, fungi and bacteria.

In 2006, the mystery of where the antifreeze glycoproteins originate in fish was solved. Although many researchers had assumed that the antifreeze glycoproteins were produced by the liver, research funded by NSF and the University of Auckland discovered that the glycoproteins originated primarily from the exocrine pancreas and the stomach.

Discovery of the antifreeze proteins has been a plus for some commercial industries. The antifreeze proteins have commercial uses. Unilever produces ice cream with the proteins to prevent freezer burn. Some cosmetic companies use the proteins in makeup, claiming they protect skin from the cold. Companies have explored using the compounds to increase freeze tolerance of commercial plants; improve farm fish production in cold climates; extend shelf life of frozen foods; and improve preservation of tissues for transplant or transfusion.



Credit: Randall Davis, Texas A&M University; images under authorization of Marine Mammal Permit No. 821-1588-01

NSF and the Department of Agriculture support research on the distribution, evolution, regulation and mode of action of antifreeze proteins.

4. Designer Genes, Arabidopsis style

Genetic plant research can lead to improved food-plant productivity; more efficient use of water in growing crops; and an increase in the raw material for biofuels to replace dwindling fossil fuel reserves and lower carbon dioxide output. Genome research provides support for integrative plant research across many species. Some of the areas that have already proven to be promising are the identification of disease-resistant genes and environmental and hormonal responses. With NSF funding, biologists first mapped all of the genes of a model organism--identifying the sequence and location of each gene and then identifying the function of each of these genes.

Credit: Rick Griffiths; composition by Barbara Corbett; Virginia Tech

NSF began working with leaders in plant biology in the 1980s to foster a spirit of cooperation and to encourage the use of model plants in research. *Arabidopsis thaliana* was selected as the first model, because it is easily manipulated and genetically tractable, and researchers were already knowledgeable about it. By studying the biology of *Arabidopsis,* researchers could gain comprehensive knowledge about the structure, organization and functions of a plant.

In 1990, NSF led a multi-agency, multinational project to identify all the genes in *Arabidopsis* by the end of 2000. Following that successful project, NSF established the Arabidopsis 2010 Project, which had the bold goal of identifying the functions of all the genes by the year 2010. The NSF-funded Arabidopsis Information Resource (TAIR) maintains a database of genetic and molecular biology data for *Arabidopsis*, including the data from the 2010 Project.

Arabidopsis research has paved the way for advances in broader plant biology. Its tools and resources have enabled the first systems-level understanding of plant gene networks and their roles in plant growth and development. Applications resulting from this work have led to commercial development of new crops with improved cold tolerance and yield. Building on the knowledge gained from *Arabidopsis*, several other plant genomes have been sequenced, including rice, maize (corn), poplar, Medicago, soybean, sorghum, and grape, and genomic tools developed. Integration of these new crop and model plant genomic resources with the tools and resources from *Arabidopsis* are enabling new insights into fundamental biological processes that in turn will inform development of plant-based biomaterials.

5. Ardi Reconstructed

Finding a skeleton of a hominid that is mostly complete is very rare and when recovered, is both exciting and extremely valuable scientifically. Only a few of these skeletons have ever been recovered: the *Australopithecus afarensis* skeleton, called *Lucy* dates to about 3.2 million years old; the *Homo erectus* skeleton called *Turkana Boy* dates to about 1.8 million years old; and in 2009, an international team of scientists announced their thrilling discovery and reconstruction of a fairly complete skeleton of *Ardipithecus ramidus,* dating to 4.4 million years old.


Credit: © T. White 2009, from Science Oct. 2 issue; (fossil housed in National Museum of Ethiopia, Addis Ababa)

Nicknamed *Ardi*, the female skeleton is 1.2 million years older than the skeleton of *Lucy*. The first fossils of *Ardi* were discovered in Ethiopia in 1994, but due to the poor condition of the bones, it took researchers 15 years to excavate *Ardi*, remove distortions digitally and analyze the bones. Researchers think *Ardi* represents a new kind of hominid, from the family that includes humans and our ancestors, but does not include ancestors of other living apes. *Ardi's* anatomy is unusual and is not similar to living apes or later hominids including *Lucy*. Her bones suggest that she walked in a primitive form of bipedalism on the ground, but supported herself on her palms and feet when in the trees. She also consumed foods indicative of woodland and forest patches, rather than those that would indicate more open environments.

There are also revolutionary implications for social structure that may be evident in the anatomy of this hominid. Scientists have interpreted the skeleton to show evidence of reduced male competitiveness. This led to the conclusion that these hominids may have lived in social units consisting of a number of couples. Males may even have helped in gathering food for sharing.

In all, 47 scientists from 10 countries contributed to the research on *Ardi* and the reconstructions of the biology and geology of the area where she lived. NSF was one of many who provided funding for this large, collaborative scientific effort.

6. Bar Codes—They're for Penguins too

Bar codes, those dizzying combinations of 30 lines and 29 spaces, are on everything from chewing gum to soft drinks, from books and newspapers to airline luggage tags and penguins. Information gleaned from bar codes helps supermarket chains, bookstores, airlines and many other industries determine what products are marketed and, sometimes more importantly, how, to whom and for what price goods are sold.

Bar codes are also used to help detect and determine consumer buying trends, literally the "why" behind consumer choices. It is estimated more than 100,000 grocery store items alone have bar codes. Scientists even tag penguins in Antarctica with bar codes to help make data gathering faster and more precise, providing help in research on migration and endangered species.

Researchers are exploring the use of bar codes in coordinating pervasive wireless sensors to revolutionalize battlefield management, intelligent transportation systems, military and civilian logistics, assistive technologies for the blind or monitor medication compliance.

Credit: © 2010 JupiterImages Corporation

NSF funding played a crucial role in the development of bar codes. In the 1970s, NSF helped fund bar-code research to perfect the accuracy of the scanners that read bar codes. In the early 1990s, research in computer vision conducted at the State University of New York-Stony Brook led to major advances in algorithms for bar-code readers. That research led to commercial development of a new product line of barcode readers that has been described as a revolutionary advance, enabling bar-code readers to operate under messy situations and adverse conditions.

Bar-code technology continues to improve. Recently, researchers developed two-dimensional bar codes that are shapes, not lines, which yield more information.

7. Dead Center—Super-massive Black Holes at the Center of the Milky Way Galaxy

The question of what lies in the center of our Milky Way galaxy has been one of astronomy's major unanswered questions. NSF-funded researcher Andrea Ghez has confirmed the presence of an enormous black hole at the center of our galaxy, providing new understanding of how galaxies evolve and surprising many astronomers, who thought it unlikely that the Milky Way, a normal galaxy with a relatively quiet center, or 'nucleus', could host an enormous black hole.


Credit: NASA and G. Bacon (STScl)

A black hole consists of a large mass compacted so densely that not even light can escape its force of gravity. Black holes are normally formed from the remnants of collapsed stars. However, near the centers of galaxies enough matter can collect from stellar collisions and the accumulation of interstellar gas to form a black hole. In 1995, using a technique in which computers analyzed thousands of high-speed, high-resolution snapshots to correct the turbulence in the Earth's atmosphere that ordinarily blurs images, Ghez was able to improve the resolution of the galactic center by at least a factor of 20. This enabled her to track the movement of 200 stars near the center of our galaxy for more than a decade. She found at least 20 stars moving as if they were in orbit around an invisible object about four million times the sun's mass. Her observations argued for the existence of the super-massive black hole at the center of the Milky Way, which suggest that most galaxies have a black hole at their centers.

8. Sustaining the Power

Developing a sustainable energy supply is one of the great challenges facing the nation. The United States relies heavily on coal, oil, and natural gas for its energy, but fossil fuels are nonrenewable. These resources are limited and will eventually become too expensive or too environmentally damaging to retrieve. For this reason, the U.S. has started to focus on clean biofuels and renewable energy sources, such as wind and solar energy, which are constantly replenished.


Credit: Bob Henson (left); U.S. Air Force (right)

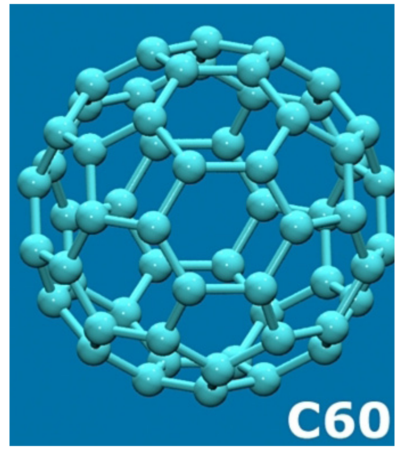
Natural gas is a relatively clean form of fossil fuel, but it can be difficult to extract from the Earth at a reasonable cost. The Marcellus black shale found throughout much of the Appalachia Basin is a huge reservoir of natural gas. In the early 1980s, an NSF-funded researcher identified and mapped the natural fractures in the Marcellus black shale, and estimated that it contains sufficient recoverable natural gas, using current technology, to meet the needs of the U.S. for almost 20 years. Researchers are investigating economically feasible ways to recover this natural gas.

Biofuels, derived from plants, are an important type of renewable fuel, but there is concern that ethanol production will consume significant quantities of grain and water resources—giving rise to serious problems. Furthermore, ethanol and some other biofuels are not fully compatible with existing cars and pipelines. NSF-funded researchers have developed an integrated process to produce jet fuel and gasoline economically from waste products such as native perennial grasses or forest waste. Researchers are also exploring ways to use algae and engineered bacteria to produce gasoline that could go directly into cars. These green gasoline alternatives would provide products that are more compatible and more energy dense than corn grain ethanol or soybean biodiesel, and would be far better for the environment.

Additionally, NSF supports research to overcome the challenges to renewable energy—ranging from developing wind turbines and integrating renewable energy into the power grid to developing new technologies for low-cost solar energy and using the power of ocean waves to generate electricity.

9. Developing New Technologies with Buckyballs

Buckyballs, developed by NSF-funded researchers in 1985, are a form of carbon-composed clusters made up of 60 carbon atoms, bonded together in apolyhedral, or a many-sided structure composed of pentagons and hexagons, like the surface of a soccer ball. Researchers discovered that you could modify buckyballs by adding or replacing an atom, which changes the properties of the buckyball.



Credit: Ivan S. Ufimtsev, Stanford University

Modified buckyballs can help to diagnose, treat and prevent serious diseases. They are being developed as antioxidants and for targeted drug delivery. Another medical application for buckyballs was found by Luna Innovations, Inc., an NSF Small Business Innovation Research grantee. Luna Innovations demonstrated that buckyballs have potential as MRI contrast agents, and as therapeutic agents for allergies, arthritis and neurodegenerative diseases such as Alzheimer's and Parkinson's.

In addition to use in the medical fields, there are a number of promising applications for buckyballs in building materials due to their sheer strength. Since buckyballs have a hardness akin to or greater than that of a diamond, buckyballs can be added to various polymers to make them strong. Due to their unique structure, heat resistance and ability to conduct electricity, applications for buckyballs range from materials that are lightweight, strong and multifunctional, to more efficient solar cells to coatings for furniture and other surfaces that protect the public from infectious diseases.

10. Speaking Out: NSF Brings Science to the Public

Since the early 1970s, NSF and its partners have been bringing cutting-edge discoveries to millions of Americans via the full range of contemporary media.

Early television productions included the widely acclaimed "NOVA Science Now" and "Discover: The World of Science". In the 1980s, numerous projects were developed to particularly excite and engage young people. The program "3-2-1 Contact" involved middle-school students in science and mathematics, especially targeting girls and minorities, and "Square One TV" brought mathematics to 8-12 year olds. "Stand and Deliver" was the story of Jaime Escalante, the Los Angeles high school mathematics teacher who fought to get inner-city minority students interested in math and science. NSF continues to inspire and educate the nation's youth with productions like "Cyberchase", a mystery-adventure cartoon for teaching mathematical problem-solving, and "Design Squad", a reality competition show for engineering projects.

Credit: © Educational Broadcasting Corporation.

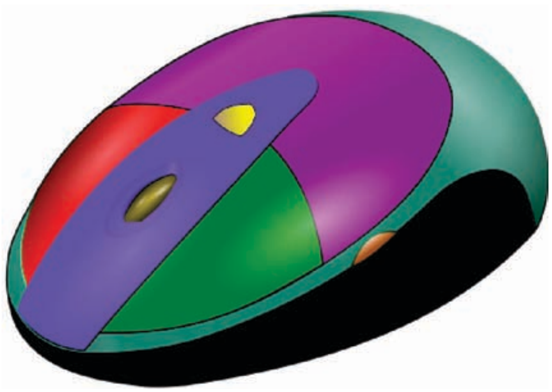
NSF-supported "Earth & Sky," one of the longest-running science radio shows in existence, and which recently launched a Spanish-language version, "Cielo y Tierra." NSF also supported the NPR science unit, bringing science to nationally distributed programs such as "Morning Edition" and "All Things Considered."

Current NSF-funded projects use a range of integrated contemporary media to support lifelong learning by public and professional audiences. For example, QUEST, a large-scale, cross-platform initiative in the San Francisco Bay Area, combines award-winning television and radio materials, original web media, community and educational outreach, and involves research institutes, science-focused organizations, and the public, to create a growing repository of science media and educational content for use both in and out of schools. Such projects are creating and evaluating models for the future of public media.

In addition, NSF has funded an extensive array of high-profile projects that support public understanding and engagement in science, via exhibitions, youth and community programs, cyberlearning, citizen science, forums, networks and other innovative formats.

11. Developing Manufacturing Innovations—CAD-CAM

Research by NSF-funded scientists on solid modeling led to widespread use of computer-aided design and computer-aided Manufacturing (CAD-CAM), which has revolutionized much of the manufacturing processes in the U.S. CAD systems allow mechanical designers to create geometric models of the parts they want to produce using computer graphics. Digital descriptions are essential for computerized manufacturing, since they can be interpreted to produce the instructions that computerized, numerically controlled machine tools use to make hardware.



Credit: Eduemoni/Wikipedia

This work enabled U.S. firms to address today's manufacturing challenges—where companies must respond quickly to rapidly changing global markets. NSF-supported research continues to provide the foundation for new manufacturing technologies that increase efficiency and allow U.S. firms to be globally competitive.

From small beginnings at Carnegie Mellon University and other institutions in the early 1970s, NSF-funded research evolved into an average total of several million dollars annually at dozens of universities. NSF was willing to support—and eventually encourage—proposals to address problems with design that neither private firms nor federal mission agencies were interested in solving. This process was seemingly instrumental to the successes realized through CAD-CAM. For example, research at the University of Rochester developed the first practical software for 3-D modeling. This advance raised quality, reduced costs and helped the U.S. regain the productivity it lost in the 1980s. A significant development has been the CAD modeling of objects as 3-D volumes, which allows the virtual assembly of products such as the Boeing 777 aircraft. With NSF and industry funding, a system to produce software was refined to the point where it would be used by industry in 1982.

Recent technical developments have fundamentally impacted the utility of CAD-CAM systems. For example, the ever-increasing processing power of computers has given them viability as a vehicle for CAD-CAM application. Another important trend is the establishment of a single CAD-CAM standard—the United States National CAD Standard. Finally, CAD-CAM software continues to evolve on a continuing basis in such realms as visual representation and integration of modeling and testing applications.

12. Water of Life

According to the National Academy of Engineering, approximately one in six people in the world lack access to adequate water and in some countries half the population does not have safe drinking water. More people die due to polluted or inadequate water supply than from war and in the near future, clean water may be the world's most valuable resource. The United Nations has identified the need for clean water as "one of the greatest human development challenges of the early 21st century." Even in the United States, the long-term water supply is under threat.

There is contamination by pesticides and heavy metals, salt water intrusion in coastal areas and inadequate replenishment of fresh groundwater.

With NSF funding, scientists are responding to this challenge by finding relatively low-cost, low-energy usage ways to obtain clean drinking water. At the Center of Advanced Materials for Purification of Water with Systems at the University of Illinois at Urbana-Champaign, researchers are investigating methods for desalination, decontamination and disinfection of water. With help from nanotechnology, the researchers have developed inexpensive, rapid and more sensitive ways of detecting and removing water contaminants including arsenic, lead and mercury.

Credit: Josh Chamot, National Science Foundation

NSF-funded researchers at the University of Texas at Austin recently developed a chlorine-tolerant membrane that could simplify the water desalination process, while increasing efficiency and lowering costs of the process.

Researchers have also developed models for analyzing watersheds and the links between water and infrastructure systems such as electricity and biofuels. Analysis from these models helps governments make more informed decisions about water and environmental and energy policies. For example, a University of Washington engineer developed a method to provide early warning and monitoring of droughts, saving states up to millions of dollars each year. Her system has already helped shape drought plans in Arizona, Georgia and Washington.

Other approaches to providing abundant, clean fresh water are being explored and developed by a number of other NSF-supported research facilities and teams from Arizona, Texas, Pennsylvania and Wisconsin.

13. Cloud Computing: Building a Platform to the Sky

Cloud computing represents a growing paradigm of on-demand access (as a service) to computing, data and software utilities, an abstraction of unlimited resources, and a usage-based billing model, where users essentially "rent" virtual resources and pay for what they use. Underlying these cloud (infrastructure, platform, data, software, etc.) services are consolidated and virtualized data centers that provide virtual machine (VM) containers hosting computation and applications from a large number of distributed users. It is anticipated that cloud platforms and services will increasingly play a critical role in academic, government and industry sectors, and will have a widespread societal impact. Accordingly, NSF is committed to providing the science and engineering communities with the opportunity to leverage highly scalable cloud computing platforms to conduct research and education activities in cloud and data-intensive computing and their applications.

Credit: Zina Deretsky, National Science Foundation

In 2007, NSF partnered with IBM and Google to provide computer science students with the necessary skills to develop cloud applications. In 2008, NSF created the Cluster Exploratory Initiative to provide NSF-funded researchers access to software and services running on the Google-IBM cluster.

These funding initiatives and partnerships were the first steps in developing new approaches to solving data-intensive problems over a wide range of scientific and engineering areas.

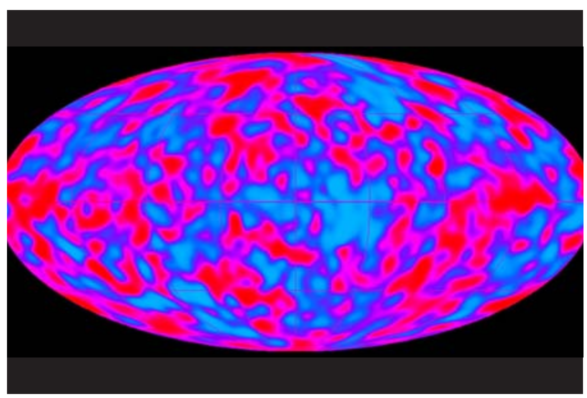
Since investigating an increasing number of research questions requires large amounts of data, from physics to medicine to economics, the main challenge for computing is how to turn those massive data sets into knowledge. To help address the need to process and respond to large amounts of data, NSF recently awarded a grant to the University of Illinois, Urbana-Champaign, to establish an experimental computing cluster with that focus. The computing cluster will be part of the HP, Intel, Yahoo! Cloud Computing Test Bed, one of the six "centers of excellence" that HP, Intel and Yahoo! are creating to promote research in data-intensive computing.

Most recently in 2010, NSF created the Computing in the Cloud (CiC) program that was based on a memorandum of understanding between Microsoft Corporation and NSF and provides the science and engineering communities with the opportunity to leverage the Microsoft Azure computing platform to stimulate research and education advances in cloud and data-intensive computing and their applications.

14. Unlocking the Universe's Origin

NSF-funded researcher George Smoot of the University of California at Berkeley shared the 2006 Nobel Prize in Physics with John Mather of the NASA Goddard Space Flight Center for their 1992 discovery of the basic form and small variations in the cosmic microwave background radiation, confirming the Big Bang theory of how the universe was created.

The Big Bang theory predicts that there should still be radiation filling the universe that is a remnant of the original explosion. The radiation would not be visible to the human eye, but would be at wavelengths that could be detected by radio telescopes. Furthermore, the radiation would



Credit: NASA / COBE Science Team (left); NASA (right)

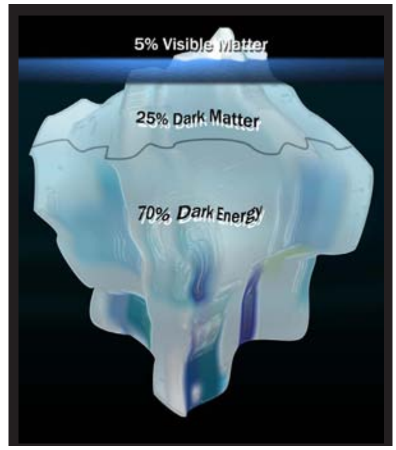
be particularly strong at a well-defined wavelength, and would exist wherever one looked (at this wavelength) in the sky. To the human eye, or using an optical telescope, the space between stars and galaxies is black, but using a radio telescope there is a faint glow that is strongest in the microwave region of the radio spectrum.

Using the Cosmic Background Explorer satellite, launched by NASA in 1989, Smoot and Mather analyzed the cosmic microwave background radiation and were able to observe the universe at an early stage, about 380,000 years after the universe was born. They detected extremely small variations in the temperature of the radiation, which offered a clue to the distribution of matter in the universe the beginning. These small variations are the seeds from which galaxies developed. Their results provided a precise test of our knowledge of the history and composition of the universe and the nature of the Big Bang. The English physicist Stephen Hawking called the results "the greatest discovery of the century, if not of all times," while a government task force called it "one of the most spectacular scientific breakthroughs in past decades." The research was also funded by the Department of Energy's Office of Science and NASA.

15. Into the Unknown: Dark Energy

In 1998, two independent teams of astronomers, both with NSF support, demonstrated that the expansion of the universe was accelerating. Although researchers knew the universe had been continually expanding since the Big Bang, this new discovery drew an unexpected picture that the universe is becoming larger at an ever-increasing rate, driven by a yet unknown force that has been dubbed "dark energy."

It was previously unknown whether the gravitational attraction between galaxies would be enough to slow down and perhaps reverse the observed expansion of the universe. However, NSF-funded astronomers Saul Perlmutter, Robert Kirshner, and Alexei Filippenko, as well as a team of astronomers at Cerro Tololo Inter-American Observatory in Chile, an NSF-funded facility, discovered that not enough matter exists to slow the pace of the expanding universe.



Credit: Courtesy of SLAC and Nicolle Rager

In the current standard model of cosmology, dark energy accounts for almost three-quarters of the total mass-energy of the universe, yet the exact nature of dark energy is still speculative. To solve this major problem in cosmology, research continues with funding from NSF, as well as from NASA and the Department of Energy.

16. Deep-Sea Drilling Reveals Youthful Sea-floor Features

In the 1950s, NSF began supporting deep-sea drilling projects to explore the ocean floor and research the geological history of the continents. In the 1960s, NSF funded the Deep Sea Drilling Project, in which NSF partnered with a consortium of marine research centers called the Joint Oceanographic Institutions for Deep Earth Sampling and the Scripps Institution of Oceanography. The first NSF-funded drill ship in the project was the *Glomar Challenger*.

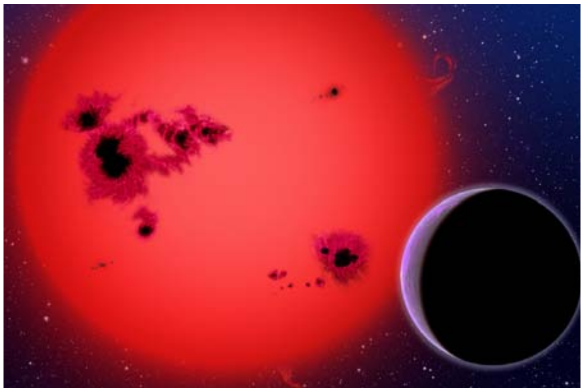
The *Glomar Challenger* retrieved samples that provided definitive proof for continental drift and seafloor renewal at rift zones; gave further evidence to support the plate tectonics theory; and demonstrated how youthful the ocean floor is in comparison to Earth's geologic history. The analysis of the samples suggested that the ocean floor could be as young as 200 million years, which is significantly younger than the 4.5 billion years of the Earth.


Credit: Integrated Ocean Drilling Program; illustration by Charles Floyd

After the *Glomar Challenger* docked for the last time, the project continued with new ships as part of the Ocean Drilling program that explored the sea floor through 2003. In 2003, the Integrated Ocean Drilling Program (IODP) was launched. The IODP is an international research program involving 24 countries to monitor, drill, sample and analyze the sub-seafloor environments. The current IODP research vessel, the *JOIDES Resolution*, launched its scientific operations in early 2009.

17. Extra Solar Planets Loom on the Horizon

Observatories and their telescopes, funded and supported by NSF, have helped to discover and identify dozens of new planets outside our solar system since NSF-funded researchers discovered the first of three extra solar planets using radio telescopes in the early 1990s. Two of these planets are similar in mass to the Earth. The third has roughly the mass of the Moon. Since these planets orbit a pulsar, the collapsed remnant of a supernova explosion, none of them is likely to support life.



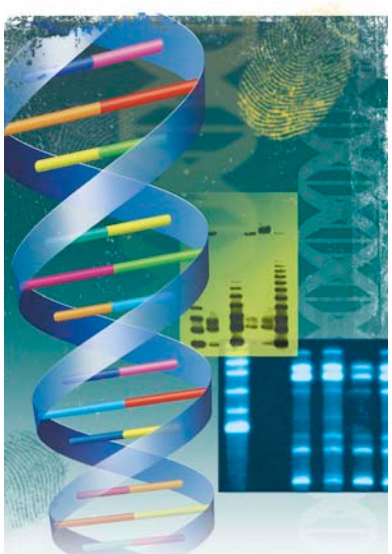
Credit: David Aguilar, Harvard-Smithsonian CfA

In 1995, an NSF-funded team of astronomers independently confirmed by optical techniques, the discovery of a fourth new planet. The following year the same team announced the optical detection of two more planets orbiting sun-like stars.

In 2009, NSF-funded researchers discovered a new "super Earth" orbiting a red dwarf star 40 light-years from Earth. A super-Earth is a planet between one and ten times the mass of the Earth. This new super Earth is about 6.5 times the mass of the Earth. What made this new discovery even more exciting was the super-Earth planet may be made mostly of water. Additionally in the same year, astronomers using the International Gemini Observatory, an NSF-funded facility, obtained images of three planets orbiting a nearby star, the first pictures of another 'solar system.'

Presently, the number of known exoplanets has risen to over 420, with major funding for the research coming from NSF, NASA and the Department of Energy.

18. The Fingerprints of Life



Credit: © 2010 JupiterImages Corporation

DNA fingerprinting, also called forensic DNA analysis was first used in a criminal investigation in England in 1986. Since then, DNA fingerprinting has become an essential part of the American legal system. NSF-funded projects in basic biological research were critical to the discovery of a microbe's enzyme that makes modern DNA fingerprinting possible.

DNA fingerprints are sequences of DNA molecules unique to each individual. The patterns of these sequences can be identified when tiny amounts of DNA are amplified with a technique known as the polymerase chain reaction (PCR).

PCR involves DNA polymerase, an enzyme that assembles DNA chains over many cycles of heating and cooling. Most DNA polymerase cannot withstand high temperatures, but NSF-supported researchers discovered a bacterium (*Thermus aquaticus*), in the hot springs at Yellowstone National Park that can tolerate high temperatures. This discovery, along with private sector research on developing a heat-resistant DNA polymerase, enabled the commercial production of PCR and its ability to amplify millions of copies of DNA in a matter of hours. Since its invention, PCR has become an essential tool of DNA analysis for forensic and other identification uses.

In addition to DNA fingerprinting, these techniques are also used to track endangered species and trace human migrations and have led to development of enzymes for non-polluting detergents.

19. Eye in the Sky

Research at the NSF-supported National Center for Atmospheric Research (NCAR) and at universities was instrumental in the development of Doppler radar as a meteorological research tool. Doppler radar is what Americans see every day on TV news and weather reporting.

NCAR and several universities made important refinements to software and hardware technologies associated with Doppler radar that enhanced its use for both research and operational purposes. Conventional radar provides information about the location and intensity of precipitation associated with a storm, while Doppler radar adds the capability to discern air motions within a storm. Doppler radar helps scientists and meteorologists see or detect near-ground wind shears, which are dangerous to aircraft, and also enables meteorologists to forecast the location and severity of weather with greater accuracy, resulting in improved public safety and, in some cases, lives saved. NSF has also been involved in the development of ground-based and airborne Doppler radars, which have been used extensively in fundamental research on meteorological phenomena from tornadoes to large winter storms.

Credit: Josh Wurman, CSWR

Beginning in 2003, NSF began funding the Engineering Research Center for Collaborative Adaptive Sensing of the Atmosphere (CASA). CASA's goal is to develop revolutionary weather-sensing networks of small, distributed and highly interconnected, low-cost Doppler radars that save lives and property by sensing the region of the lower atmosphere, currently below conventional radar range, where most severe weather such as tornadoes forms. These new networks will map storms, winds, rain, temperature, humidity, and the flow of airborne hazards, and transmit the information to end users in time to make necessary decisions.

20. Supply and Demand

Over the years, NSF has supported researchers whose work has transformed economic policy. This support is clearly demonstrated by the fact that over 40 winners of the Nobel Prize in Economics have been NSF grantees. In fact, every winner of the prize since 1998 received NSF funding for his or her research.

For example in 2004, Finn Kydland and Edward Prescott shared the Nobel Prize in Economics for their contributions to macroeconomics, particularly in addressing the time-consistency problem in formulating economic policy and in understanding the causes of business cycles. Kydland and Prescott changed the way economists thought about the design of economic policy and the causes of business cycles, both transforming economic research and influencing the practice of economic policy in general and monetary policy in particular. They demonstrated that what at first seems to be an optimal policy today may not be time consistent. Government policies often demand that future government actions will impose a political cost on the government. When that happens, governments will not want to stick

Credit: Comstock Images/Getty Images

to the announced, seemingly optimal policy, leading to credibility problems. Prescott and Kydland demonstrated that real, supply-side shocks—such as a hike in the price of oil or hurricanes hitting Florida or the invention of a new technology—by and large account for the ups and downs in the business cycles in a well-functioning economy.

In 2009, Elinor Ostrom and Oliver Williamson shared the Nobel Prize in Economics for their research contributions on how groups of people cooperate. Ostrom's research demonstrates that common property can be managed by users, even in the absence of a strong central authority. Her work challenges the conventional thought that common property is not well managed and should be privatized or highly regulated. To determine her findings, Ostrom conducted fieldwork in a variety of group settings such as user-managed fish stocks, lakes and groundwater basins. Williamson's research illustrates that business firms can represent governance structures that can be used in conflict resolution. His work demonstrates that, especially when market competition is limited, firms are in a better position to resolve conflict than markets.

21. Fire and Brimstone

Beginning in the early 1960s, NSF-funded research conducted at the Hubbard Brook Experimental Forest in New Hampshire identified acid rain and its effects. In the late 1980s, NSF began supporting a Long-term Ecological Research (LTER) site at Hubbard Brook Experimental Forest. This research led to important changes in the 1990 amendments to the Clean Air Act.


Credit: © University Corporation for Atmospheric Research (left); courtesy of the Long Term Ecological Research (LTER) Network (right)

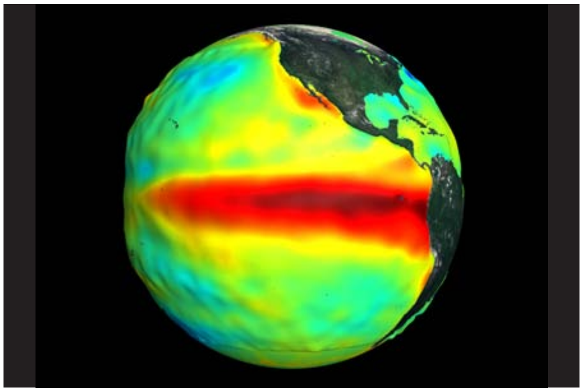
Acid rain is caused primarily by the burning of high-sulfur coal and oil used to fuel electric power plants. Emissions from these sources are transported through the atmosphere and deposited on locations downwind through rain, snow, sleet, and hail and via dry deposition of acidifying gases and particles from cloud and fog water. Acid rain is considered a widespread, regional phenomenon in eastern North America, the Scandinavian countries, China and elsewhere throughout the world.

The long-term effects of acid rain include harm to freshwater ecosystems, with notable reduction in biodiversity; widespread decline in forest health, including damage to more than 70 percent of the red spruce forests in parts of New England; and destruction of building materials. Recent research funded by NSF, along with NASA and NOAA, has shown the impact of acid rain on coastal waters, which possibly could threaten the entire ocean ecosystem.

22. Mother Nature Simmers with Latin Spice

NSF played a major role in supporting the basic research that led to the Tropical Oceans Global Atmosphere (TOGA) program. Launched in 1985 by the World Meteorological Organization with contributions from 16 nations, the TOGA program helped answer the questions of how fundamental physical processes that couple or connect the tropical Pacific Ocean and the atmosphere work and how to make those processes predictable. In the United States, TOGA was a multiagency effort involving NSF, NOAA, NASA and the Office of Naval Research.

Even before TOGA, meteorologists and oceanographers, funded by NSF's Division of Ocean Sciences, set out to test the hypothesis that the El Niño Southern Oscillation (ENSO) cycle, which includes both El Niño and La Niña phases, can be predicted.

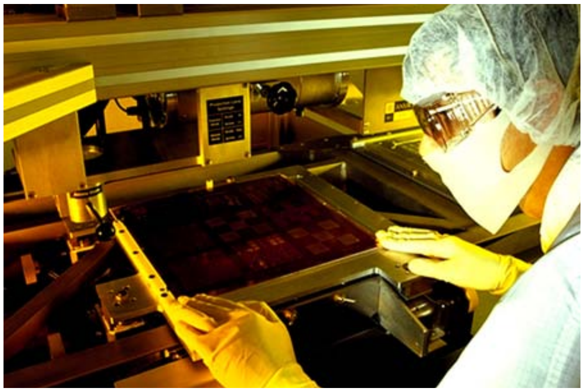
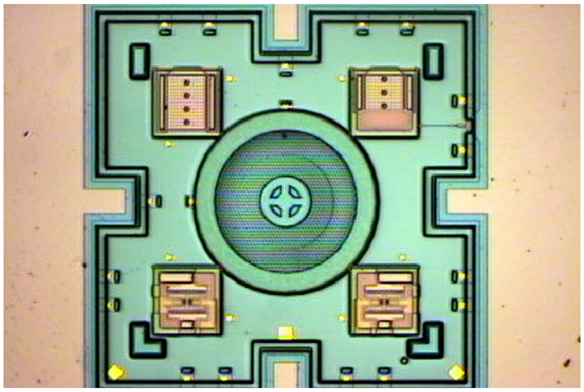

Credit: NASA/Goddard Space Flight Center; the SeaWiFS Project and ORBIMAGE; Science Visualization Studio

The main benefit of the TOGA program is that more accurate and useful predictions of El Niño/La Niña weather cycles can be conducted up to two to three seasons, or about nine months in advance. Predictions of El Niño (the warming) and La Niña (the cooling) of tropical Pacific Ocean waters are now providing extra months of preparation, helping to lessen economic and human losses that often result from these events.

23. Centers of Knowledge

NSF-funded centers such as Engineering Research Centers (ERCs) and Science and Technology Centers (STCs) play a key role in driving discovery at the frontiers and developing creative solutions to societal problems. The centers bring together experts from different fields to tackle complex issues and train the next generation's leaders in research and innovation.

The ERCs foster highly productive, long-term industry-university research collaborations and develop knowledge about innovative processes and products in a broad spectrum of advanced technologies. For example, the bioengineering ERCs have developed new technologies ranging from implantable devices that enhance sight, hearing, and movement to special robots that assist surgeons to scaffolds that promote the growth of skin and bone. Manufacturing and processing centers have developed new



Credit: Courtesy Georgia Tech's Center for Low Cost Electronics Packaging Research, photo by Stanley F. Leary (left); NSF Engineering Research Center for Wireless Integrated MicroSystems, University of Michigan (right)

approaches to engineering design and novel manufacturing processes that allow companies to respond quickly and effectively to changing global markets. Other centers have focused on topics ranging from minimizing damage from earthquakes to producing biorenewable chemicals and developing new approaches to renewable electric energy and offshore oil production. NSF's support for the ERCs has had a significant impact on their academic fields, on industry and on society through new approaches to research, and through the development of new processes, products, companies and jobs.

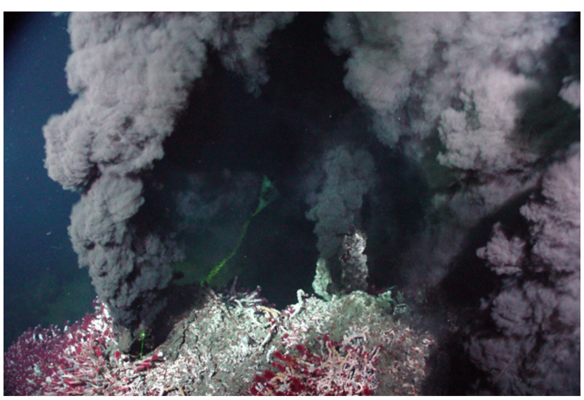
NSF supports on average, 15-20 ERCs at any given time. For example, the Synthetic Biology Engineering Research Center (SynBERC) seeks to develop engineered biological systems that will be an impetus to new technologies for processing information, producing energy, manufacturing chemicals and pharmaceuticals and fabricating materials. Using synthetic biology—engineering yeast and *E. coli* bacteria—the Principal Investigator, Jay Keasling, has developed a simple and cost-effective method for producing anti-malarial drugs. Low-cost drugs are desperately needed by more than 300 million people worldwide who are afﬂicted by malaria. SynBERC is making rapid progress in building biological modular "parts" with specific performance characteristics and making them available through open inventories to researchers worldwide.

NSF expanded the centers idea beyond engineering with the creation of the STC program in 1987. The objective of the STCs is to encourage technological transfer and innovative approaches to interdisciplinary problems, while supporting basic research and education. Currently, there are 17 STCs located at prestigious universities around the country. Research conducted at the STCs ranges from materials, meteorology, and electronics to computers, biotechnology and environmental management.

Centers have proven to be powerful tools in solving current problems and training young researchers to solve the problems of the future. One indicator of the importance of these centers to the American science and engineering enterprise is the number of breakthroughs and discoveries that have resulted from research conducted at the ERCs and STCs.

24. Extremophilia

Life has proven to be more resilient and more varied than had been imagined just a few years ago. NSF-funded research has shown that living organisms can be found in what had been thought to be impossibly hostile environments, including extremely arid deserts, highly acidic fluids and extremes of heat and cold. These organisms have been termed extremophiles. Examples of extremophiles that researchers have found include bacteria deep in a South African gold mine that survive by "eating" the byproducts of radioactivity; other bacteria that survive the winters at Antarctica; cells that can go dormant in arid conditions for 20 years, but can revive in the presence of water; single-celled archaea thriving near hot, undersea vents that convert hydrogen sulfide into food; and organisms which have evolved to live in highly acidic conditions.




Credit: University of Washington, Center for Environmental Visualization (left); Nicolle Rager Fuller, National Science Foundation (right)

The discovery of extremophiles demonstrates the diversity of life on this planet and contradicts previous theories that these kinds of extreme environments could not support life. Moreover, finding extremophiles on Earth living in hostile environments revolutionizes the search for extraterrestrial life. The conditions under which a planet might support life are now much broader and the possibility of finding life has increased. If microbial life can survive a foot below the terrain of Chile's Atacama Desert, one of the driest places on Earth, then there is a better possibility for life in extremely dry environments, including Mars. Research into this question is being funded by NSF and NASA.

25. Solving the Insolvable

After 350 years, the challenge laid down by the French mathematician Pierre de Fermat in the 1630s was met by Princeton University's Andrew Wiles. Professor Wiles proved that there are no positive integers for which $x^n + y^n = z^n$ when n is greater than 2.

A key piece to the puzzle fell into place in 1986, when mathematician Ken Ribet showed that solving a modern problem in math, called the Taniyama-Shimura conjecture, would allow you to prove Fermat's Last Theorem. There was one small hitch: no one was really sure how to approach the Taniyama-Shimura conjecture, or whether it was even provable at all. With support from NSF, Wiles devoted seven years of his career to Fermat's challenge.

Credit: © C. J. Mozzochi, Princeton N.J

Wiles' demonstration of Fermat's simply stated proposition is more than a hundred pages of complex math. However, within the complexity, the proof had more practical significance—not because of Fermat's Last Theorem itself, which despite its 350-year pedigree is more of an intellectual curiosity, but because of the route Wiles took to get there. The Taniyama-Shimura conjecture connects two previously unrelated branches of mathematics—number theory (the study of whole numbers) and geometry (the study of curves, surfaces and objects in space). Wiles' proved a special case of the conjecture to solve Fermat's theorem and in 1999, a team of mathematicians built on Wiles' work to prove the full conjecture.

Proving Fermat's Last Theorem has had a number of impacts on the field. First, it related two previously unrelated branches of mathematics, number theory and geometry. Secondly, the demonstration sparked numerous developments in number theory and arithmetic geometry. Finally, and maybe most importantly, Wiles proving Fermat's Last Theorem excited a whole new generation of young scholars interested in pursuing mathematics.

26. The Age of En"light"enment

Optical fiber has been a critical component in the ongoing communications revolution, especially after the emergence of the Internet and other high-speed data applications. The cable TV industry, long-distance telephone services and computer networks all rely on advances in fiber optics to deliver their product to consumers. Over 1 billion kilometers of fiber have been installed worldwide, enough to circle the globe more than 25,000 times.

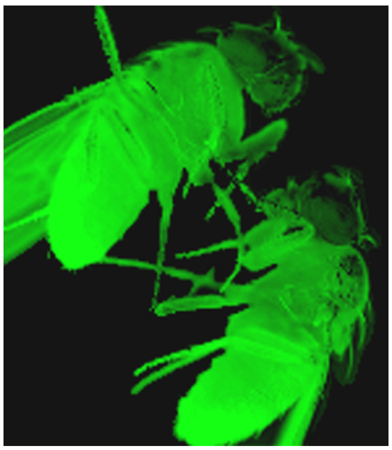
While industry played a lead role, NSF-funded research on solid-state physics, ceramics/glass engineering and other areas was essential to the development of optical fibers. Additionally, federal funds helped train doctoral scientists and engineers in industrial research and development on optical fibers and related components such as semiconductor lasers, and by supporting basic research at materials engineering centers. In addition, NSF supported optical communications research in two areas with strong academic bases: integrated electro-optics and network theory.

Credit: © 2010 JupiterImages Corporation

Fiber optics is an example of how basic research funded by NSF gets transformed into a commercial endeavor by private industry. The insight into how to transmit light over long distances via optical fibers was done using NSF funds, after which industry leaders Corning and AT&T transformed the idea into a practical technology. Thus, NSF played an important role in supporting research relevant to the development of the nonfiber components and devices needed in a fiber-optic communication system. Without these components, advances in the fiber alone could not have produced the communications systems that we enjoy today.

27. Sleep Tight, Don't Let the Bedbugs Bite

Humans have always measured their existence by outward signs of the passage of time—day and night or sunrise and sunset. Commonly referred to as a 24-hour clock or circadian rhythm in humans, a cluster of cells in the brain regulates our metabolism, digestion and the sleep-wake cycle.



Credit: Steve A. Kay, the Scripps Research Institute

Gaining control of this clock, researchers claim, could produce many benefits, including lowering blood pressure, improving drug metabolism, overcoming jet lag and helping shift workers function more effectively. But, as often happens in science, key tools that are now making it possible to understand the clock's mechanism came from an unexpected direction. Research begun in the early 1950s led to identifying the compound luciferase as the enzyme responsible for the bioluminescent "fire" of fireflies. Decades later, researchers at the University of California-San Diego isolated and cloned the luciferase gene and subsequently developed a new molecular probe by attaching the luciferase gene to other genes in plants and animals. This technology allowed scientists to measure activities of specific genes of interest under natural conditions and opened up a whole new way to study how genes regulate life processes.

Researchers at the NSF Science and Technology Center at the University of Virginia and other locations were able to use the luciferase technology to show periodic cycling as a luminescent glow when "biological clock" genes turned on and off in living plants and animals. These plants and animals, with well-studied genes, include the mustard plant *Arabidopsis thaliana* and a fruit fly species (*Drosophila melanogaster*). This research has allowed new ways to precisely monitor clock gene activity and has increased our understanding of the importance of human beings' internal 24-hour clock and its role in everyone's daily life.

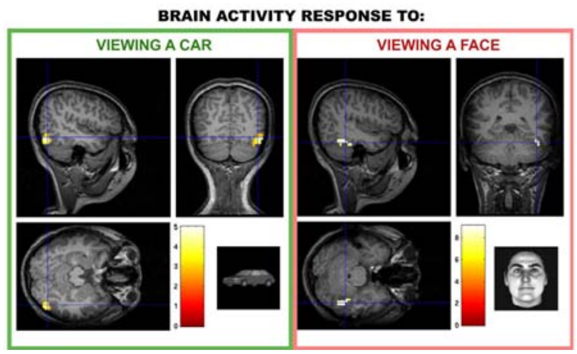
Recently, researchers at the Scripps Research Institute, the University of Virginia and Brandeis University have called into question that our internal 24-hour clock is centrally controlled by the brain. Using the fruit fly as a model, researchers found clock genes in tissues throughout the body that were controlled locally. This recent finding may shift our thinking about the 24-hour clock, increase our understanding of daily rhythms associated with drug metabolism, and could lead to the development of more effective treatments for disorders associated with the 24-hour clock, such as jet lag, shift work and seasonal depression.

28. X-Ray Vision Not Just for Superheroes

Magnetic resonance imaging (MRI) is a noninvasive imaging method that uses a powerful magnetic field and radio frequency pulses to image most internal structures. MRI technology was made possible by combining information about the spin characteristics of matter with research in mathematics and high-flux magnets. It relies on the physics of nuclear magnetic resonance (NMR) and on the core technology of NMR spectrometry, measuring the wavelengths of a spectrum. Fundamental research, supported by NSF, led to the development of MRI technology, now widely used in hospitals to detect tumors and internal tissue damage in patients and to investigate differences in brain tissue.

Functional magnetic resonance imaging (fMRI) measures the hemodynamic response or change in blood flow and blood oxygenation that is related to neural activity in the brain. fMRI enables physicians and researchers to image human brain function and understand the connection between the physical brain and cognition. Additionally, fMRI is used prior to neurosurgery to show individual brain function maps of the cortical areas close to a tumor before surgery.

Since the development of fMRI in the early 1990s, NSF has supported numerous fMRI studies that have resulted in a deeper understanding of human cognition across a spectrum of areas, including sensation, perception, motor control, memory, empathy, language and emotion. Additionally, NSF has funded the development of new statistical methods necessary for the analysis and interpretation of fMRI data. In 1999, NSF helped launch the National Functional Magnetic Resonance Imaging Data Center (fMRIDC) at Dartmouth University. Now funded by the National Institutes of Health and maintained at the University of California, Santa Barbara, the fMRIDC provides a publicly accessible repository of studies and data to further the study of the human brain.



Credit: Maximilian Riesenhuber, Georgetown University Medical Center

The fMRI is an excellent example of how NSF funding supports technological innovation and medical advances. NSF supported the underlying NMR, as well as research in other areas directly related to the development of MRI technology, such as electromagnetics, digital systems, computer engineering, biophysics and biochemistry.

29. A Burst of Heavenly Fire

Until recently, little had been known about the “fireballs” known as gamma ray bursts. Since their discovery about 30 years ago by defense satellites, these intense cosmic outbursts seemed to occur randomly around the sky about once per day.

In 1997, a team of astronomers using a pair of NSF radio telescopes made the first measurements of the size and expansion of gamma ray bursts. These scientists have learned the fireball is actually debris that expands at very nearly the speed of light. In these events, enormous amounts of energy are released within a very small region, which is considered much less than the typical distance separating stars.


Credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA)

The cause of gamma ray bursts is still unknown, but is likely due to the explosion of a very massive star. One burst in 1997 lasted for only 15 seconds, but emitted an afterglow that lasted several days. Study of the afterglow revealed the initial explosion released more energy during 15 seconds than the sun will release in its entire 10-billion-year lifetime, making it one of the most energetic events known to have occurred since the Big Bang. Optical studies reveal the 1997 gamma ray burst was at least seven billion light-years away. Because of their short duration, gamma ray bursts are difficult to “catch.”

In 2009, an international team of astronomers discovered high-energy gamma rays emitted by the starburst galaxy M82. The observed gamma rays have energies that are more than a trillion times higher than the energy of visible light and are the highest energy photons detected from a galaxy undergoing large amounts of star formation. This new finding could help unlock the mystery of the origin of cosmic rays.

30. The Changing Earth and Sky

Researchers funded by NSF have discovered signs of a changing climate in nearly every corner of the globe, from the icy expanses of the polar regions of Earth to its equatorial ecosystems. Our planet's climate affects—and is affected by—the sky, land, ice, sea, life, and the people found on Earth. To piece together the entire puzzle of climate change—what we know, what we still have to learn and what humankind can do to prepare for the future—we must study all of the physical, natural and human systems that contribute to and interact with Earth's climate system.

Credit: Top row: David Cappaert, Bugwood.org, © University Corporation for Atmospheric Research; © 2009 JupiterImages Corporation. Second row: Eva Horne, Konza Prairie Biological Station; © 2009 JupiterImages Corporation (2). Third row: © 2009 JupiterImages Corporation; Jeffrey Kietzmann, National Science Foundation; © Forrest Brem, courtesy of NatureServe; Digital Vision, Getty Images. Fourth row: Jim Laundre, Arctic LTER; © 2009 JupiterImages Corporation; by Lynn Betts, USDA Natural Resources Conservation Service; Peter West, National Science Foundation. Bottom row: David Gochis © University Corporation for Atmospheric Research; © University Corporation for Atmospheric Research
Design by: Adrian Apodaca, National Science Foundation

As researchers work together to solve the climate puzzle, they are revolutionizing the way we understand the Earth system as a whole. Researchers have realized that they must reach across disciplinary boundaries to study questions that extend beyond any one field of science or engineering. In fact, because of the complexity of Earth's climate, this research involves contributions from nearly every field of science, math and engineering.

Ecologists have noted marked changes in the habitats of the species they study—changes in the places where they find a particular species, changes in the dates plants first sprout and bloom, changes in plant growth rates and even signs of evolutionary adaptation brought on by a warming climate.

Ocean scientists have recorded higher temperatures and rising ocean acidity, which alter the characteristics of the most fundamental organisms of the ocean food chain. Coral reefs—some of which have thrived for centuries—have died off suddenly as a result of ocean temperatures that exceed the corals' ability to survive.

Polar scientists have watched vast tracts of Arctic sea ice melt away, leaving behind more open water than anyone can remember seeing during any previous Northern Hemisphere summer. Glaciologists have witnessed ice shelves—once thought too large to be influenced by anything short of a cataclysmic environmental change—break up into a churning sea of icebergs in a matter of days.

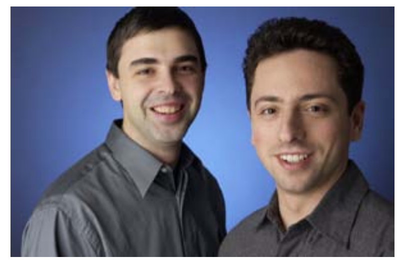
Social scientists have recorded the bewilderment of indigenous people. Their cultural knowledge, which stretches back in time through numerous generations, holds no record of the kinds of environmental changes they are encountering today.

Paleoclimatologists have discovered—through tree ring data, ice cores, and other corroborating records—that the concentration of carbon dioxide and Earth's average temperature are nearing levels that have not been reached for hundreds of thousands of years.

31. Just "Google" It

It is difficult for most of us to remember an Internet before Google, but in the early 1990s, the Internet had fewer than 100 Websites and people looked for them without a search engine. Even with a low number of sites, the need for accessible interfaces to this growing data collection became clear. To solve this problem, NSF led the multi-agency Digital Library Initiative (DLI). In 1994, the DLI made its first six awards and included in those awards was a Stanford University project led by professors Hector Garcia-Molina and Terry Winograd. These early awards were submitted before the World Wide Web exploded and before Web search tools had been developed.

The first Web search tools included Yahoo!, started by two Stanford students, and Lycos and WebCrawler. These early search engines began indexing Web pages focused on keyword-based techniques to rank the results from the search. Another Stanford student, Larry Page, along with Sergey Brin, who was supported by an NSF Graduate Student Fellowship, created a new way to search the Web as a collection and to crawl from page to page by following links. Page uncovered how important Web page ranking was and recognized that the act of linking one page to another required conscious effort, which was evidence of human judgment about the link's destination. Their new engine prototype could map out a vast family tree reflecting the links among the pages. To calculate rankings on the tree, they developed the PageRank method that would rank a Web page higher if other highly ranked Web pages linked to it.



Credit: © 2010 Google

Their prototype, BackRub, was funded by the DLI project and other industrial contributions. By the end of 1998, Page and Brin received outside funding and incorporated into Google, Inc. The PageRank method survives as one of the main components in today's Google search engine.

32. Educating Tomorrow's Scientific Giants

To ensure human capital for science, technology, engineering and mathematics, NSF has run the Graduate Research Fellowship (GRF) program since 1952. The graduate research fellowships are three-year fellowships for graduate study resulting in a master's or doctoral degree in the science, technology, engineering or mathematics fields.

Since the creation of the program, NSF has funded over 42,000 graduate research fellowships. In the 2009 competition, NSF-funded graduate research fellows came from over 300 different baccalaureate institutions and are enrolled at approximately 140 different graduate institutions. Additionally, the GRF program is a tool to reinforce diversity in science and engineering. During the past three years, over 50 percent of the awardees were women and approximately 15 percent were underrepresented minority students.

The GRF program has been successful at selecting individuals who will complete their training and become scientific leaders in their fields. The program has a high rate of doctoral degree completion—more than 70 percent of graduate research fellows complete their doctoral degrees within 11 years.

Credit: Doug Levere, University at Buffalo

The record of the NSF GRF program is impressive. The Chairman of the Federal Reserve Bank, Ben Bernanke, Google co-founder Sergey Brin and Freakonomics coauthor Steven Levitt are past fellows, as well as numerous Nobel laureates, including the Secretary of Energy Steven Chu.

33. Ticks in the "Lyme" Light

Lyme disease is the most common tick-borne disease in North America and Europe and one of the fastest-growing infectious diseases in the United States. Lyme disease first emerged in 1975 when a rash of cases plagued the town of Lyme, Conn. It was not until 1982 that the cause was determined to be bacterial in nature. Lyme disease can affect multiple animal species, from humans to dogs, from deer to skunk. The bacteria can also be passed from mother to fetus through the placenta during pregnancy. NSF-funded research on Lyme disease has led to basic discoveries regarding the risk of human exposure and effective control of that risk.

Credit: Graham Hickling, University of Tennessee-Knoxville (left); Scott Bauer, Agricultural Research Service, USDA (right)

Lyme disease incidence is rising in the U.S., and is in fact far more common than West Nile virus and other insect-borne diseases. Forest fragmentation could explain the increase. Over the past 16 years, scientists have found that forest patches, common in cities, suburbia, and some rural areas, often have more Lyme disease-carrying ticks, which could increase the risk of human exposure to the disease. While forest fragments generally have fewer species than continuous habitat does, some species actually fare better in small patches. Ticks are one of these species, largely because the host species of the bacterium that causes Lyme disease, the white-footed mouse, has larger populations in fragmented forests due to low predator and competitor populations. Ticks feeding on these mice are at least twice as likely to become infected (and therefore dangerous) as are ticks that feed on any other mammal or bird host.

This NSF-funded research is important because it provides a novel way of looking at the transmission of diseases, and demonstrates that human health is affected by the local ecology, and by land-use practices. For any given disease that is spread by an animal, at least four species are intimately involved: the human victim, the pathogen, the vector and at least one wildlife reservoir. By studying the interconnectedness of these species in real landscapes, scientists can trace potential disease routes. The ability of ecologists to predict disease risk is leading to better education of the public about when and where they are most at risk and how to avoid exposure to this and other tick-borne diseases. Avoidance is particularly important in light of the lack of a Lyme disease vaccine, poor diagnostic accuracy and problems with post-exposure treatment.

34. Science's Global Generation

The science and engineering enterprise is increasingly global. Today's research requires globally engaged investigators working collaboratively to advance the frontiers of knowledge and to apply the results of basic research to long-standing global challenges such as epidemics, natural disasters and the search for alternative energy sources.

As societies and nations grow increasingly interdependent, international research partnerships are growing in importance. The ability to develop collaborations that create new value for the partners is often the limiting factor for progress in critical areas of science, engineering and technology. International scientific partnerships that foster cooperation, build global research capacity and advance the frontiers of science can provide benefits to scientists, academic institutions and nations throughout the world. NSF has played a significant role in advancing such international scientific partnerships thereby increasing the collaborative advantage of participating U.S. researchers and institutions.

A few examples of international scientific collaborations include *inter alia*, the Materials World Network (MWN), the Partnerships for International Research and Education's Africa Array project and the Global Ring Network for Advanced Application Development (GLORIAD). Working jointly with counterpart national, regional and multinational funding organizations worldwide, MWN has increased and enhanced opportunities for collaborative research activities in materials research and education between U.S. investigators and their colleagues abroad. These collaborations have contributed to major advances in condensed matter physics, solid state and materials chemistry, polymers, biomaterials, metallic materials and nanostructures, ceramics, electronic and photonic materials, and condensed matter and materials theory. The Africa Array project has been instrumental in building collaborative research networks and facilitating infrastructure development for geoscience

Credit: Materials World Modules Program, Northwestern University (left); GLORIAD (right)

research in Africa. These activities are enabling a much better understanding of the Earth's mantle beneath eastern and southern Africa and are strengthening scientists' ability to understand local geohazards and to locate valuable geo-resources such as minerals and water. GLORIAD's cyber-connectivity activities have dramatically improved existing U.S. science-dedicated network links with China, Russia, Korea, Canada and the Nordic region, and with the recent extension through the "Taj" connection, have brought U.S. researchers broadband collaborative potential with researchers in India, Singapore, Hong Kong and Egypt.

35. Researchers Work Across the Globe

As far back as 1990, NSF supported linkages between the U.S. and international research and education communities and supported partnerships to assist other countries in connecting to the global Internet. In 1997, NSF established a program to connect new and existing networks in other countries with the U.S. academic research community and institutions. By early 1999, about 15 countries—as well as other agency's advanced networks —had been interconnected at the Science, Technology and Research Transit Access Point (STAR TAP), in Chicago. STAR TAP was the first interconnection point for the exchange of high-speed network traffic among research institutions worldwide, built and managed by a partnership including the University of Illinois at Chicago and the National Center for Supercomputing Applications (NCSA) at the University of Illinois at Urbana-Champaign.

NSF has supported high-performance connections between the U.S. and Europe, the Asia-Pacific region, Latin America, China, Russia, and other countries. Over the last decade, the number and size of these connections have grown, and the number of network exchange points has similarly expanded.

The increased network capacity and connectivity has opened the door to exciting new global initiatives across the sciences. The adoption of cyberinfrastructure tools is changing the practices of science towards network-dependent collaborations to support data-intensive science. This phenomenon has started to accelerate as a result of the NSF-funded International Research Network Connection (IRNC) links, providing a high-availability science and engineering research and education production environment. Supported scientific initiatives with the U.S. span countries and continents. Examples include: (Europe) The Large Hadron Collider, whose particle physics experiments engage dozens of universities in the U.S.; (South America) large astronomy observatories and instruments in Chile are now leveraged remotely by astronomy students and researchers; and (Asia-Pacific) environmental, biological, and geological studies requiring interaction with sensors and other instruments for bird migrations in China, tsunami early warning systems in the South Pacific, and earthquake-related shake tables in Japan. Several of these individual projects can produce enough data alone to congest a 10 gigabit-per-second link.

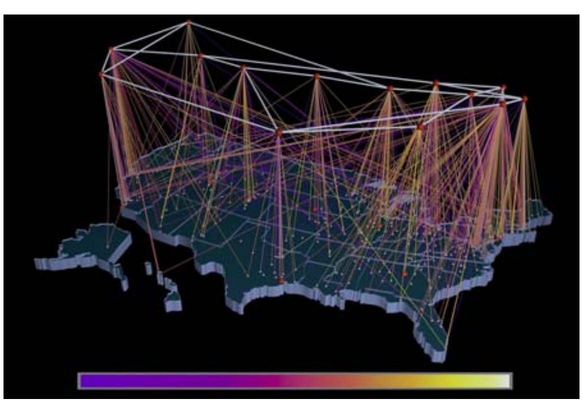

Credit: National Science Foundation

Today, a rich and diverse high-speed fabric of multi gigabit connections devoted to supporting international collaborations in scientific and engineering research and education span the globe, with NSF continuing to support the global networking needs of U.S. academic research and education

36. Surfing the Information Superhighway

Internet technology began with government-funded networking efforts, including NSF's NSFNET that have now matured and spurred vast commercial development. From the beginning, computer networks were expected to expand the reach and grasp of researchers, providing better access to computer resources and easier transfer of information. NSF made this expectation a reality.

The first "Internet" was the interconnection of unrelated networks consisting of the Advanced Research Projects Agency's ARPANET, run by the Defense Advanced Research Projects Agency (DARPA), in 1977. Over the next decade, increasing NSF involvement led to a three-tiered system of internetworks that were managed by a mix of universities, nonprofit organizations and government agencies. By the mid-1980s, primary financial support of the Internet had been assumed by NSF. The increasing demand for advanced networking and research computing capabilities was met by NSFNET and the foundation's Partnerships for Advanced Computational Infrastructure (PACI). In March 1991, the NSFNET acceptable use policy was altered to allow commercial traffic.


Credit: Donna Cox and Robert Patterson, courtesy of the National Center for Supercomputing Applications (NCSA) and the Board of Trustees of the University of Illinois

Creation of NSFNET was an intellectual leap. It was the first, large-scale implementation of Internet technologies in a complex environment of many independently operated networks. NSFNET forced the Internet community to iron out technical issues arising from the rapidly increasing number of computers and address many practical details of operations, management and conformance. NSF leadership played a major role in NSFNET's use of TCP/IP, a decision that influenced the evolution of the Internet and its protocol foundation. Throughout its existence, NSFNET carried, at no cost to institutions, any

U.S. research and education traffic that could reach it. At the same time, the number of Internet-connected computers grew from 2,000 in 1985 to more than 2 million in 1993.

In the years following NSFNET, NSF helped navigate the road to a self-governing and commercially viable Internet during a period of remarkable growth. The year 1998 marked the end of NSF's direct role in supporting maintenance and management of the Internet. That year, the network access points and routing arbiter functions were transferred to the commercial sector. Since then, NSF has continued to support research, development and experimental deployment of new Internet technologies and protocols. Over the years, NSF has been instrumental in providing international research network connections to Europe, Russia, South America and the Pacific Rim.

In addition to the Internet, the world's first freely available Web browser originated from NSF-funded research at the National Center for Supercomputing Applications (NCSA) at the University of Illinois, Urbana-Champaign. This Web browser allowed browsers to view Web pages that included both graphics and text. Called "Mosaic," it spurred a revolution in communications, business, education and entertainment that has had a trillion-dollar impact on the global economy. With a graphical browser, programmers began to post images, sound, video clips and multi-font text within the Web's hypertext system. Less than 18 months after its introduction, Mosaic had become the Internet "browser of choice" for more than a million users and set off an exponential growth in the number of Web servers and surfers.

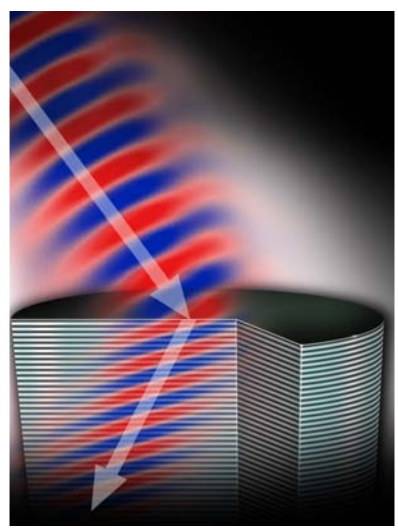
37. Harry Potter Science

Some aspects of the world of Harry Potter may soon be possible. With funding from the NSF and the U.S. Army Research Office, scientists have made major strides in developing invisibility cloaks.

In 2008, researchers developed metamaterials—composite materials with extraordinary capabilities to bend electromagnetic waves—to hide 3-D objects. Metamaterials deflect radar, light, or other waves around an object, rather than scattering it, so none of the waves reflect back to the eye or other receiver. These cloaks only worked for one color and for very small objects.

Another development in cloaking technology developed by NSF-supported researchers was a "tapered optical waveguide" (mirrored conduit) that works for all the colors of the spectrum and cloaks objects 100 times larger than those rendered invisible by the metamaterials.

Recently, NSF-funded researchers have developed an active cloaking method that uses devices that generate electromagnetic fields rather than being composed of metamaterials that passively shield objects from electromagnetic waves. The new method is two-dimensional, but the researchers believe it can be easily extended to three dimensions, which means real objects could be cloaked. Active cloaking, unlike passive cloaking using metamaterials, can cloak objects from a broader band of wavelengths.



Credit: Keith Drake

Although not close to the invisibility cloaks used by Harry Potter or the Romulan spaceships in "Star Trek," these new invisibility cloaking methods might be able to shield submarines from sonar, planes from radar and buildings from earthquakes.

38. Kid's Stuff: Science and Technology Education

In the early 1950s, there was widespread recognition that science and mathematics teachers in elementary through high school lacked sufficient knowledge of the subject matter for effective science, technology, engineering and mathematics (STEM) teaching. Beginning as a small experiment in the summer of 1954, NSF has funded a variety of programs that provide professional development in STEM subject areas for hundreds of thousands of teachers. The first efforts were summer and academic year institutes for practicing teachers. Those programs provided refresher courses for teachers who had been left behind by the rapid changes in scientific knowledge; basic training for teachers who had had inadequate preparation in the first place; and reorientation so that teachers could effectively teach new curricula being introduced.

More recent NSF investments in preparation and professional development of STEM teachers have taken the form of local and state systemic change programs and the current Math Science Partnership (MSP) program. The concept of teacher institutes has been redeveloped as *Institute Partnerships: Teacher Institutes for the 21st century*, enlisting K-12 teachers and school systems in entirely new relationships with science and mathematics faculty from colleges and universities. These institutes encourage teachers to rethink mathematics and science education in the classroom and to develop leadership skills to be used in their schools, districts and states. The MSP program also supports Targeted Partnerships, which focus on studying and solving teaching and learning issues within a specific grade range or at a critical juncture in education, and/or within a specific disciplinary focus in mathematics or the sciences. In all of its work with schools, NSF emphasizes evaluation of progress for teachers and students, as well as research on innovative practices that can be adopted by the field of STEM education.

Credit: Barry Myers

Almost from the beginning, NSF's national efforts to improve STEM education in K-12 schools has included supporting projects designed to develop, test, and disseminate innovative curriculum materials. NSF funds were critical resources for post-Sputnik projects in mathematics, physics, biology, chemistry and general science. In the more recent standards era, NSF funds enabled 13 major projects in mathematics and over 40 projects in science and technology to produce comprehensive curriculum materials that support innovations in elementary, middle and high-school STEM instruction.

Those curriculum development projects produced student text materials, resources for teachers and a variety of supporting materials (assessments, laboratory materials, etc.) with the aim of: (1) introducing discipline-based science, technology and mathematics ideas to the school curriculum; (2) demonstrating new ways of organizing and presenting familiar content; and/or (3) supporting innovative ways of teaching STEM content and assessing learning. Recent STEM curriculum development projects have also produced innovative technologies to enhance student explorations learning, and problem solving in science, technology, engineering, and mathematics, and are actively translating new insights from the learning sciences into improved strategies for teaching and assessing learning of STEM content and thinking processes.

Taken together, the sustained NSF investment in teacher and instructional materials development has been the primary national engine of innovation in U.S. STEM education for over 55 years.

39. Beyond the Falling Apple

The Laser Interferometer Gravitational-Wave Observatory (LIGO) is designed to confirm the existence of gravity waves, a basic and still mysterious cosmic force predicted by Albert Einstein nearly 100 years ago. Einstein described space and time as different aspects of reality in which both are ultimately the same. The presence of large amounts of mass or energy distorts the space-time and is observed as gravity. When large masses move suddenly, some of this space-time curvature ripples outward. Gravity waves are created during the collision of stars and other heavy objects in the universe. They are believed to affect space as well as objects in much the same way a dropped pebble disturbs the surface of a quiet pond.


Credit: LIGO Laboratory, California Institute of Technology

Using a laser interferometer, the LIGO facilities can detect the ripples in space-time. The laser interferometer is like a microphone that converts gravitational waves to electrical signals. LIGO consists of two nearly 2.5-mile long installations located at Hanford, Wash. and Livingston Parish, La. LIGO should be able to detect and measure gravitational waves out to distances of 70 million light years.

Funded by NSF, LIGO was designed and constructed by a team of scientists from the California Institute of Technology, the Massachusetts Institute of Technology and by industrial contractors. Construction of the facility was completed in 1999. Initial operations of the detectors began in 2001, and represented an advance over all previous searches of two or three orders of magnitude in sensitivity and in bandwidth. LIGO has provided insight into the nature of the universe shortly after the Big Bang.

In order to increase sensitivity, Advanced LIGO was launched in 2008 and is scheduled for completion in 2014. Once completed, Advanced LIGO will have an increase in sensitivity by more than a factor of 10 over LIGO.

LIGO is a vital tool in understanding the origins of the universe. Measurements made by LIGO were used to probe the gravitational wave background in the beginning of the universe. Using Advanced LIGO, researchers will have an opportunity to see gravitational waves from the Big Bang at significant orders of magnitude.

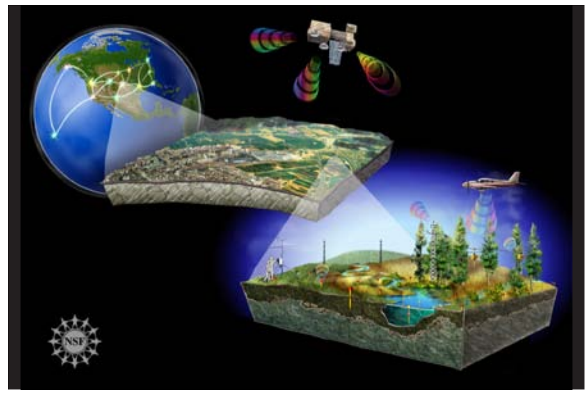
40. The Web of Life—And Ecological Research Too

NSF has funded research on ecology from its beginning. During the last few decades, NSF funded two cooperative efforts to gather long-term data that would eventually lead to the accurate prediction of the consequences of human or natural perturbations to ecosystems. These two efforts represent two different ways NSF encourages large-scale, cooperative research to solve major problems.

In 1980, NSF established the Long Term Ecological Research (LTER) Network to support research on long-term ecological phenomena in the United States. LTER is a collaborative effort involving more than 1800 scientists and students investigating ecological processes over long temporal and broad spatial scales. It is a collection of individual investigator projects aligned with common themes, but remaining individual research projects.

Throughout the 30 years since its inception, the LTER Network has promoted collaborative ecological studies across the globe. Funding for the LTER program has produced results that include a better understanding of tropical soil ecology, which has vast implications in the agricultural and forestry communities of land management and conservation. Studies of predator-prey interactions over four decades have revealed information vital to conservation efforts and to long-term sustainability efforts for worldwide ecosystems. One 20-year study of greenhouse gas emissions from agricultural and forestry services found that these emissions can be mitigated by certain land management strategies. Lessening the amount of greenhouse gas emissions will have economic and environmental impacts. Finally, one long-term study in the southwestern United States is looking at how ecological factors, such as vectors, influence the transmission of certain hantavirus. Results of the LTER analyses are being used to develop rodent/virus sampling strategies and disease prevention plans for human populations.

In contrast, the National Ecological Observatory Network (NEON) is a centrally operated user facility. Planning for NEON began in the late 1990s to collect ecological and climatic observations across the continental U.S., including Alaska, Hawaii and Puerto Rico. This unique network will enable



Credit: Jim Laundre, Arctic LTER (left); Nicolle Rager Fuller, National Science Foundation (right)

researchers to both detect and forecast ecological change across decades. The focus of the network will be on the impact of climate change, land-use change and invasive species. The continent has been divided into 20 eco-domains, each representing a distinct ecosystem. NEON passed the final design review in Nov. 2009, and should be detecting environmental signals as early as 2012.

41. Come Fly with Us

Credit: © University Corporation for Atmospheric Research, photo by Wendy Schreiber

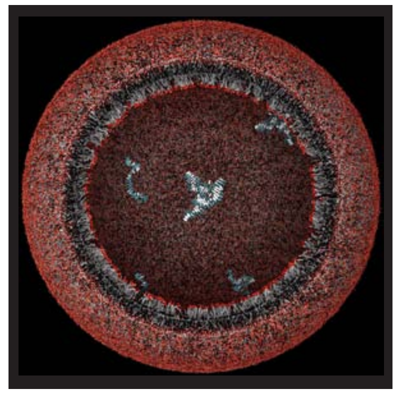
Microbursts are intense, sometimes violent, yet highly localized downward and outward bursts of wind at relatively low atmospheric levels. Winds can gust at speeds approaching 150 miles per hour, and can be particularly dangerous for aircraft that are taking off or landing. Prior to research funded by NSF, it was estimated that approximately 650 lives had been lost in the U.S. alone in 20 airline accidents attributed to microbursts.

Until the mid-1970s, most researchers believed that downdrafts would substantially weaken before reaching the ground and not pose a threat to aircraft. They blamed tornadoes and gust fronts as the primary causes of storm damage. In 1977, NSF supported the NIMROD (Northern Illinois Meteorological Research on Downburst) project in collaboration with the National Center for Atmospheric Research (NCAR). More recently, NIMROD has been followed by further NCAR collaborations with the Federal Aviation Administration (FAA), the National Oceanic and Atmospheric Administration (NOAA) and researchers from a number of universities.

Data collected by these NSF-funded projects has led to the widespread agreement that microbursts exist. The projects' findings helped demonstrate to the FAA and international aviation authorities that radar-warning systems to detect wind shear threats and to institute worldwide training programs were needed. As a result, the FAA's Terminal Doppler Weather Radar was installed at major airports throughout the country, and pilots are now required to take microburst and wind-shear training courses and practice maneuvers in flight simulators. Due to these new safety precautions and training, the risk to pilots and passengers from microbursts has been significantly reduced.

42. Life Before Life Was Known: Prehistoric Cells

There are no physical records of what the first primitive cells on Earth looked like or how they grew and divided. To understand the origins of life and how Earth's earliest cells may have interacted with their environment approximately 3.5 billion years ago, scientists have turned to making models of the earliest cells. A team of researchers at Harvard University, funded by NSF, NIH and NASA, modeled a primitive cell, or protocol, that is capable of building, copying and containing DNA in the laboratory.



Credit: Janet Iwasa, licensed under a Creative Commons (CC) Attribution-Noncommercial-No Derivative Works 3.0 United States License

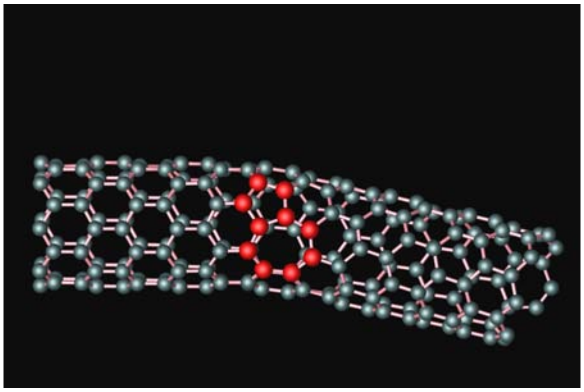
The model of this primitive cell has a fatty acid membrane that allows for chemical compounds, like the building blocks of DNA, to enter the cell without the help of protein channels and pumps, which are required in present-day modern cells. Additionally, this primitive cell would not use enzymes for copying DNA. It has been proposed that ancient hydrothermal vents may have been sites where prebiotic molecules—molecules made before the origin of life, such as fatty acids and amino acids—were formed. In this theoretical scenario, fatty acids are formed on the surface of minerals deep underground, and then brought to the surface by the eruption of a geyser. When fatty acids are in an aqueous environment, they spontaneously arrange so their hydrophilic (or water-loving) "heads" interact with the surrounding water molecules and their hydrophobic (or water-fearing) "tails" are shielded from the water, resulting in the formation of tiny spheres of fatty acids called micelles. Micelles can convert into layered membrane sheets or enclosed vesicles. Researchers commonly use vesicles to model the cellular membranes of protocells.

This model of the earliest cell demonstrates how these early cells could replicate and, given time and the right environment, could evolve into more complex forms. Moreover, the model gives us insight into how primitive cells emerged from simple chemicals and are an important piece in answering the larger question of how life arose on Earth.

43. Good Things Come in Small Packages

Imagine roads that sense the flow of traffic, bridges that sense cracks on their decks before they become visible, or networked sensor systems that provide point-of care diagnostics, or remote monitoring of toxic chemicals and threats. These are just a few of the benefits that can be achieved through nanotechnology. Nanotechnology also offers the potential for revolutionary advances in areas such as individualized pharmaceuticals, new drug delivery systems, more resilient materials and fabrics, safer and more effective industrial catalysts, order-of-magnitude faster computer chips, and sustainable development in water and energy resources.

All living systems are governed by molecular processes at the nanoscale. Nanotechnology allows us to control matter on an atomic and molecular scale to create materials, devices and systems with new properties spurring advances in science, engineering, technology and innovation with potentially profound implications for society.



Credit: Vin Crespi, Pennsylvania State Physics. Distributed under the Creative Commons license http://creativecommons.org/licenses/by-sa/2.0/

Nanotechnology uses nanoscale processes to create products by arranging the molecules of various shapes and surface features to form patterns that give rise to novel and useful features and functions. These patterns define important material properties such as electrical conductivity, optics and mechanical strength.

NSF has been a pioneer in fostering the development of nanotechnology, establishing an appropriate physical infrastructure and workforce to realize the opportunities presented by nanotechnology. For example, the NSF-funded National Nanotechnology Infrastructure Network (NNIN) is an integrated network of 13 university-based laboratories that provide shared access for researchers across the country to nanotechnology resources and expertise. NNIN enables rapid advances at the nanoscale through efficient access to infrastructure, and has facilitated discoveries in the areas of efficient solar energy, diagnostic screening and high-performance imaging systems.

44. Looking to the Stars

For 50 years, NSF has provided American and International astronomers access to several world-class observatories, including the International Gemini Observatory, the National Optical Astronomy Observatory (NOAO), the National Radio Astronomy Observatory (NRAO) and the National Astronomy and Ionosphere Center that operate large optical and radio telescopes and radar facilities. Research in ground-based optical, infrared, radio and radar astronomy and solar physics is conducted at NOAO and NRAO facilities including the four-meter optical telescope at Arizona's Kitt Peak and Cerro Tololo and Pachon in northern Chile, the 10 separate antennas of the Very Long Baseline Array (VLBA) telescope spaced across the continent from St. Croix in the east to Mauna Kea in Hawaii, the 27 antennae of the Very Large Array (VLA) telescope in the New Mexico desert, the Robert C. Byrd Green Bank Telescope in West Virginia, and solar telescopes on Kitt Peak and on Sacramento Peak in New Mexico. NSF's support of these facilities ensures that a broad range of U.S. scientists and students will have access to these facilities. Furthermore, these observatories also provide leadership for the next generation of astronomical facilities such as the Atacama Large Millimeter Array, a new radio astronomy facility under construction in Chile, and the Advanced Technology Solar Telescope, the new flagship for ground-based solar astronomy to be built atop Haleakala on Maui.

Credit: Dave Finley, NRAO/AUI/NSF

From studies using these national facilities, scientists and the public first learned that the distribution of galaxies in the universe is lumpy and that galaxies existed billions of years ago. The first gravitational lens, a foreground galaxy that gravitationally distorts the image of a more distant galaxy behind it, was discovered at Kitt Peak. Three teams of radio scientists have used NSF's VLBA radio telescope to learn new details about how sun-like stars are formed. A different team of radio astronomers has used the VLBA to make the most accurate measurement ever taken of the distance to a faraway galaxy and its precise measurements are revising the picture of our own Milky Way Galaxy. Discoveries made using NSF's VLA telescope have ranged from the surprising detection of water ice on Mercury to the first detection of radio emission from a gamma ray burst. The results of research conducted with the VLA fill thousands of pages in numerous scientific journals and are cited throughout modern astronomy textbooks.

Researchers at these observatories have gathered and continue to gather information about the evolution, composition and variations among protostars, stars, clusters, planetary nebulae, novae and

X-ray binaries, as well as the structure and distribution of galaxies and quasars, and the structure and evolution of the universe itself. Virtually every branch of contemporary astronomy has been advanced by the national telescope facilities.

45. Down and Dirty

Soil contamination with heavy metals or organic chemicals is a worldwide problem, with estimates for the cost of soil cleanup in the billions of dollars just in the United States alone. Soil contamination impacts human health—including abnormal numbers of cancer cases--the ecosystem and agriculture. The traditional solution has been to transport massive amounts of contaminated soil to hazardous waste landfills.

Credit: © 2010 JupiterImages Corporation

But in the last decade there has been a concerted effort to develop a new, more cost-efficient and less disruptive solution for rehabilitating heavy-metal-contaminated environments using biotechnology. Phytoremediation is a method of using plants to degrade, remove or stabilize toxic compounds from contaminated soil and water. Phytoremediation provides an ecologically sound and safe method for restoration and remediation. Although some plant species are capable of accumulating heavy metals, the levels of removal are not generally effective for large-scale cleanup. However, researchers successfully engineered bacteria that adhered to the plants' rhizomes and absorbed the target pollutants in significantly greater quantities.

Working with a number of government partners as part of the Joint Program on Phytoremediation, NSF has funded research to understand the basic biology behind phytoremediation, including trying to understand how the plants manage to act on the contaminants from the genetic level.

Biomediations, like phytoremediation, are examples of green technologies that will become increasingly more important in the coming decades.

NSF-supported researchers have developed new technologies for detecting and monitoring problems with contamination. For example, the Center for SubSurface Sensing and Imaging Systems, an NSF Engineering Research Center headquartered at Northeastern University, developed a high-resolution electrical conductivity measurement system to image radioactive pollution plumes that were invisible to conventional seismic measurements. This made it possible to begin remediation before the area was seriously contaminated.

Nanotechnology is the basis for efficient new approaches to remediating groundwater chlorinated by organic compounds. Researchers have synthesized novel co-polymers that aid in transporting iron nanoparticles to the contaminated areas where they remediate the organic compounds. Similarly, newly designed nanoparticles of gold and palladium were shown to be a highly effective catalyst to remediate trichloroethylene—a solvent used to degrease metals and electronic parts.

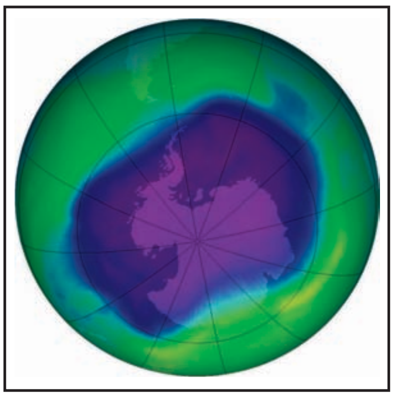
46. It's a Bird! It's a Plane! No, It's an Ozone Hole!

In May 1985, British scientists reported a steep drop, over several years, of austral springtime ozone in the atmosphere above Halley Station, Antarctica. The surprise phenomenon came quickly to be known as the Antarctic ozone hole. Their report suggested that manmade chemicals (principally chlorofluorocarbons, or CFCs) might be far more damaging to the world's protective layer of stratospheric ozone than had been expected.

Within months of the initial 1985 British report, NSF delivered ozone sensors to McMurdo and Amundsen-Scott South Pole stations in Antarctica to measure ozone loss as a function of altitude. In 1986, a research team including scientists from academia, NOAA and NASA went to McMurdo research station to measure not only ozone, but also the chemicals that affect it, and established that the chemistry of the stratosphere above McMurdo was abnormal. They showed that levels of chlorine compounds were remarkably high.

United Nations' representatives meeting in Canada in 1987 produced the Montreal Protocol, which is phasing out production of CFCs in industrialized countries. This treaty is the first to address the Earth's environment. By 2009, essentially every member of the United Nations had signed the protocol, and they had reduced their consumption of ozone-depleting substances by some 95 percent.

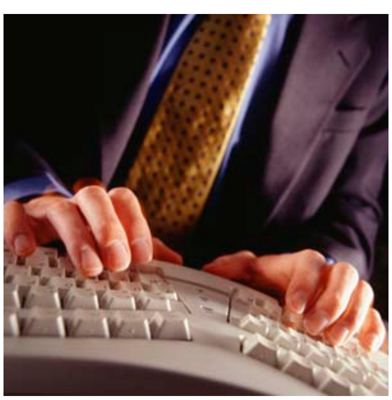
Monitoring has shown that chlorine compounds in the atmosphere have leveled off and begun to decline. The stratospheric ozone layer has not yet healed, but thinning has slowed. If countries continue to meet their Montreal Protocol goals, scientists anticipate recovery between about 2060 and 2075. Environment Canada projects world savings (1987-2060) of $224 billion in reduced damage to fisheries, agriculture and materials—and human health benefits as 129.1 million fewer cataracts, 20.6 million fewer cases of skin cancer, and 333,500 fewer skin cancer fatalities. The EPA estimates that, in the United States from 1990 to 2165, protecting the stratospheric ozone layer will produce $4.2 trillion in health benefits and prevent 6.3 million premature deaths from skin cancer.


Credit: NASA

Paul J. Crutzen, Mario J. Molina and F. Sherwood Roland, the three professors who had explained that the ozone layer is sensitive to anthropogenic emissions, were awarded the 1995 Nobel Prize in Chemistry. Susan Solomon, the leader of the expeditions to Antarctica establishing that anthropogenic chlorine depletes stratospheric ozone, received the 1999 National Medal of Science—the Nation's highest scientific honor. The Du Pont Company, America's biggest producer of CFCs, replaced them with a more benign compound and was awarded the 2002 National Medal of Technology –the Nation's highest honor for technological innovation.

47. All Access Pass

Grants from NSF, along with efforts by the Department of Education, helped to ensure at a crucial point in the history of the World Wide Web, that information on the Web was more widely accessible to people with disabilities. Launched in 1997, the Web Accessibility Initiative, funded by NSF, and the Department of Education, along with private donations, focused on making information and services on the Web more available and accessible, allowing disabled persons to work, conduct commerce, do research and participate in educational efforts and social interactions on the Web more fully.


Credit: © 2010 JupiterImages Corporation

In recent years, NSF has continued to support research that focuses on improving access to the Web for persons with disabilities through targeted studies that develop new products and programs. One example is DO-IT (Disabilities, Opportunities, Internetworking and Technology), at the University of Washington, which seeks to increase participation of individuals with disabilities in challenging academic programs such as those in science, engineering, mathematics and technology. Primary funding for DO-IT is provided by NSF, the Department of Education and Washington State.

48. High-tech Auto Makeover

Automobiles are now lighter and more fuel efficient, as well as safer and less expensive to operate than they were a generation earlier. These advances are due in large part to reaction injection molding (RIM).

RIM involves the high-speed mixing of two or more reactive chemicals, such as prepolymers, as an integral part of injecting them into a mold. The mixture flows into the mold at a relatively low temperature, pressure and viscosity. Curing occurs in the mold, again at relatively low temperature and pressure. The entire process, from mixing to demolding, typically takes less than a minute. The process is faster and much more energy efficient than casting. RIM results in lighter replacements for structural steel, such as strong and resilient plastics of the kind found in car bumpers and other shock-resistant or shock-absorbing products. This technology brings substantial cost savings to automobile owners through reduced repair and insurance costs and reduced fuel consumption. Public benefits accrue from reduced air pollution as well.

Credit: © 2010 JupiterImages Corporation

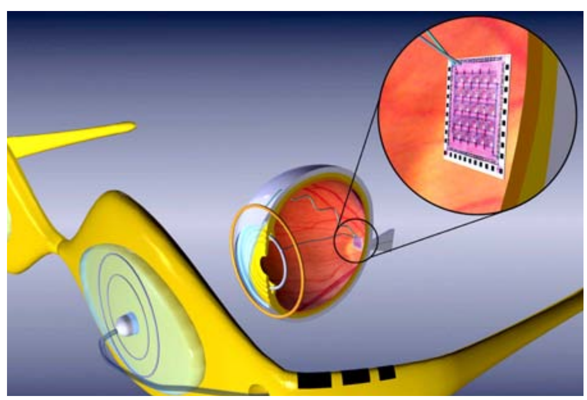
In partnership with industry, the NSF has supported RIM research since the 1970s. This research support has resulted in the development of processes, software and a generation of students familiar with the process.

Currently, NSF is funding projects that are investigating the area of reaction injection modeling in the area of reactive polymer processing.

49. Bionic Eyes: Better, Stronger, Faster

NSF has supported research to develop a retinal implant that could bring vision back to some of the 6 million Americans who suffer from retinal degenerative diseases.

Researchers have been working on producing an artificial vision system that can electronically capture and transmit images to the brain to create sight. One example of a retinal prosthesis comes from the NSF-funded Engineering Research Center at the University of Southern California. This retinal prosthesis includes electrodes implanted in the human retina along with external components. The retina chip or electrodes implanted in the human retina, picks up images from an array of photosensors and translates them into electrical signals sent to nerve cells in the retina. The external components include a camera, image processing units, electronics and a multi-channel electrode array. The camera transmits the image to the computer chip, which is connected to tissue in the back of the eye, or the retina, and then transmits the signals to the brain. The goal of the retinal prosthesis is to produce useful vision in the blind. Complete sight or near-perfect sight restoration is the long-term goal of these types of projects.

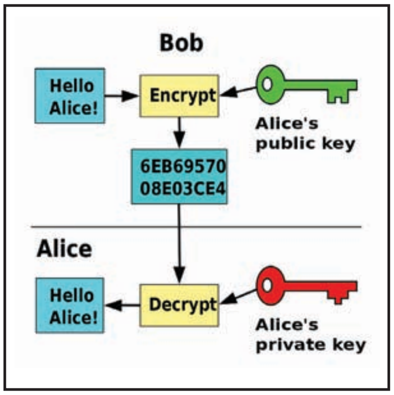


Credit: Intraocular Prosthesis Group at Johns Hopkins University and North Carolina State University; illustration by Jerry Lim

Researchers have begun implanting retinal prosthesis in blind people. This research has allowed patients who had not seen light to see light and to make out some shapes and sizes, suggesting remaining neurons in the eye can be artificially activated.

50. Spreading the Code

Secret and secure communication has always been an important tool in the arsenal of militaries and governments and in sensitive private communication. Beginning in the 1970s, NSF-funded researchers led a paradigm shift in secret and secure communication.



Credit: David Göthberg, Sweden

Prior to the 1970s, the process of secret and secure communication meant that the communicating parties had to know each other and set up secret keys and encoding and decoding procedures prior to communicating. But with the development of public-key cryptography, users could publish their public keys, just as one would publish one's phone number in a telephone directory. This meant that a secure communication user no longer needed prior contact with the focus of their communication. Rather, users could send secret and secure messages simply by using the other person's public key. This process also makes the task of encoding a message an infeasible computational task for any possible eavesdropper of the encoded message.

This public-key cryptography technology is what makes eCommerce, a significant and growing fraction of our economy, possible today. Public-key cryptography also allows us to mimic online many primitives that we have in the physical world, such as the ability to sign online documents so that the signer can be properly held responsible for signing the document, while no one else can forge the signature.

51. With a Grain of Salt

Due to contamination of high levels of salt, almost one-third of the irrigated land on Earth is not suitable for growing crops. More farmable land is lost through high-salt levels in soil than is gained through the clearing of forest resources. This is particularly an issue in areas with high usage of irrigation, like California, or areas with saline groundwater, like Egypt or Israel.

Credit: Scott Bauer, Agricultural Research Service, USDA (left); Richard Wang, Agricultural Research Service, USDA (right)

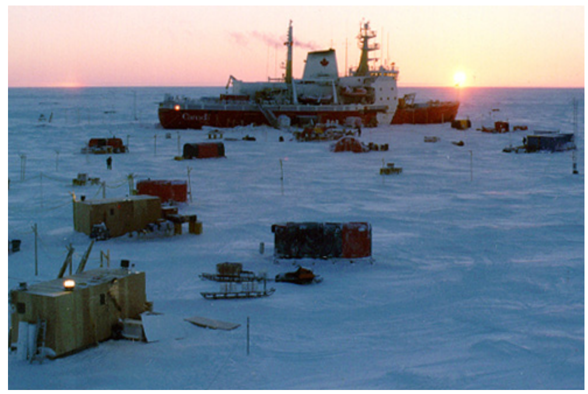
Most plants are highly sensitive to salty conditions, which cause stress and significant biochemical change due to absorption and influx of sodium from the salty soil. However, NSF-funded scientists are studying approaches that will lead to plants that can tolerate salty growing conditions, which could make it possible to reclaim some of the farmland lost through high salt levels in the soil.

In recent years, it has become clear that cells of higher plants are capable of adjusting to high levels of salt. In fact, if exposed in a gradual manner, plants can grow and reproduce during exposure to very high concentrations of sodium. What distinguishes salt-tolerant species from susceptible plants is the ability to use or "turn on" this process when necessary. By understanding the signaling system that allows a plant to sense excess sodium in the environment and then make necessary adjustments, plant biologists will be able to influence the growth of crop plants in arid and inhospitable conditions.

In 2001, an NSF-funded team of Purdue University scientists discovered the protein and gene responsible for allowing salt to enter plants. Although obstacles still remain, the expectation for this breakthrough is that it will lead to the creation of plants that are resistant to the salt found in saline soils and groundwater.

52. Listen to the Ice

SHEBA (Surface Heat Budget of the Arctic Ocean) was a large interdisciplinary, interagency (NSF and ONR) endeavor led by NSF that focused on two goals: (1) to understand quantitatively the ice albedo and cloud radiation feedbacks, and (2) to use this understanding to improve climate models. The scientific objectives of SHEBA included: (1) To develop accurate physical and mathematical relationships between the state of the ice cover and albedo for any given incident short-wave radiation, (2) To determine how the state of the ice cover changes in response to forcing from the atmosphere and the ocean, (3) To relate the surface forcing to conditions within the atmospheric and oceanic boundary layers, (4) To extend the relationships determined in Objectives 1-3 from local scales to the aggregate scales suitable for climate models, and (5) To establish a basic data set suitable for developing and testing climate models that incorporate the processes studied under SHEBA. The Arctic sea ice cover is an interactive element in the global climate system and is also a great impediment to shipping routes across the top of the world between Atlantic and Pacific industrial centers. Researchers hoped to learn more about the processes influencing the fate of the ice pack, and to improve projections of its future state.



Credit: Courtesy of U.S. Army Cold Regions Research and Engineering Laboratory

The centerpiece of SHEBA was the year-long drift of an icebreaker frozen into the Arctic ice pack. More than 180 researchers participated in the field campaign spending from a few weeks to six months in the field. The focus was to sample, over an annual cycle, the physical properties of the atmosphere, ice, and ocean of an area equivalent to a grid cell in high resolution climate model. The project used satellites, aircraft, weather balloons, icebreakers, autonomous buoys, cloud radars and lidars, and through cooperation with the operational Navy a nuclear submarine. SHEBA was the largest undertaking in the Arctic by NSF-supported researchers.

A primary legacy of SHEBA is its dataset. More than a decade after the field campaign ended, SHEBA observations are still being used to develop and improve the treatment of Arctic sea ice in large-scale models.

53. Friends and Neighbors

NSF funds several longitudinal surveys and panel studies that provide researchers with data on how American society functions and changes over time.

The Panel Study of Income Dynamics (PSID) is a longitudinal study of a representative sample of individuals (men, women and children) and the family units in which they reside. It emphasizes the dynamic aspects of economic and demographic behavior, but its content is broad, including sociological and psychological measures. As of 2010, the PSID had collected information on almost

Credit: Panel Study of Income Dynamics (PSID)

70,000 individuals spanning as much as 43 years of their lives. The PSID data sets have been central in research and knowledge building in key areas such as intergenerational relations; income, poverty, savings and wealth; demographic events such as teen childbearing, marriage and divorce, living arrangements and mortality; labor market behavior; and the effect of neighborhoods.

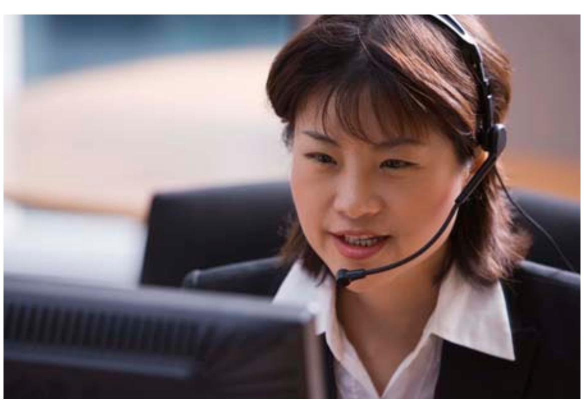
The American National Election Studies (ANES) is a collaboration between Stanford University and the University of Michigan and provides high-quality data on voting, public opinion and political participation. The mission of the ANES is to explain election outcomes by providing data that support rich hypothesis testing, maximize methodological excellence, measure many variables, and promote comparisons across people, contexts and time. Such data are critical because these citizens' actions determine election outcomes. Every year since 1948, presidential year pre- and post-election studies have been conducted using face-to-face interviewing of a nationally representative sample of adults, with an unusually high response rate. The longevity of the ANES time-series greatly enhances the utility of the data, since measures can be pooled over time, and both long-term trends and the political impact of historical events can be identified.

Since 1972, the General Social Survey (GSS) (with NSF support) has conducted 27 in-person, cross-sectional surveys of the adult household population of the U.S. with approximately 53,043 respondents. GSS content is wide ranging with approximately 5,366 variables overall. The GSS provides reliable, valid, generalizable and comparable measurements of conditions and trends in the U.S., with broad topical coverage on behavioral items such as group membership and voting; personal psychological evaluations, including measures of happiness, misanthropy and life satisfaction; and attitudinal questions on such public issues as abortion, crime and punishment, race relations, gender roles and national spending priorities. GSS data allows us to monitor and explain trends, changes and constants in attitudes, behaviors and attributes and examine the structure and functioning of society in general as well as the role of various sub-groups; and compare the U.S. to other societies by developing cross-national models of human society. The GSS Web site is extremely popular with users, having over 4 million visits annually.

54. Computers Finally Speaking our Language

Much of the early research leading to the development of speech activation and recognition technology was funded by NSF and the Defense Department's DARPA. This technology has helped computer users with physical disabilities in their use of and ability to communicate via computers and e-mail, as well as to control other devices. This initial research led to further product development from Dragon, AT&T, IBM and other companies.

Speech recognition technology has served three distinct purposes. First, it has been a benefit for computer users with physical disabilities. It has increased their ability to use and communicate via



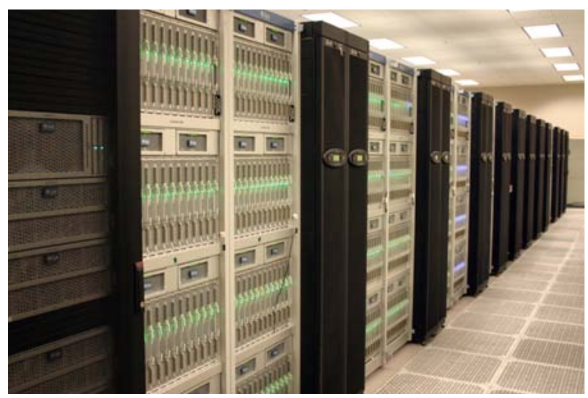
Credit: © 2010 JupiterImages Corporation computers and e-mail, as well as to control other devices. Second, it also has become an application useful to those without disabilities in such diverse settings as medical offices, where it is used by physicians for medical dictation, and in automobiles, where it enables the driver to have hands-off control over various functions. Finally, the research behind the technology has improved understanding of how humans produce and perceive speech.

NSF continues to fund ongoing research that focuses on ways to develop natural interactions with computers using speech. It is estimated that more than tens of thousands of users benefit from this technology. Although highly successful, challenges for this technology still remain. Among the challenges are developing forms of the technology which operate successfully in adverse acoustic environments or in a setting with multiple speakers using multiple dialects.

55. Supercomputing Speed Demon

Beginning in 1985, NSF committed itself to "making impossible research possible" by funding five supercomputer centers at Cornell, Princeton, the University of California at San Diego, and the University of Illinois, and a joint center at Carnegie Mellon and the University of Pittsburgh. These centers enabled a broad cross-section of academic and industrial researchers, regardless of discipline or funding agency, to model everything from atoms combining into molecules to the structure of the early universe.

Twelve years later, NSF met the increasing needs of the research community by providing funding for two consortia, the National Computational Science Alliance and the National Partnership for Advanced Computational Infrastructure (NPACI). These partnerships involved nearly 100 sites across the country in efforts to make more efficient use of high-end computing in all areas of science and engineering. In



Credit: Courtesy of Indiana University, based on illustration by Nicolle Rager Fuller, National Science Foundation (left); TACC, The University of Texas at Austin (right)

addition to giving researchers access to the most powerful computing resources available, the partnerships were instrumental in fostering the maturation of grid computing and its widespread adoption by the scientific community and industry. Grid computing connects separate computing resources in order to apply their collective power to solve computationally intensive problems.

In 2000, NSF embarked on a series of "terascale" initiatives to acquire: (1) computers capable of trillions of operations per second (teraflops); (2) disk-based storage systems with capacities measured in trillions of bytes (terabytes); and (3) networks with bandwidths of billions of bits (gigabits) per second. A year later, NSF funded a Distributed Terascale Facility. Aptly named the TeraGrid, this 11-member partnership deploys the world's largest, fastest, and most comprehensive distributed infrastructure for general scientific research. Researchers from over 200 institutions currently utilize its facilities.

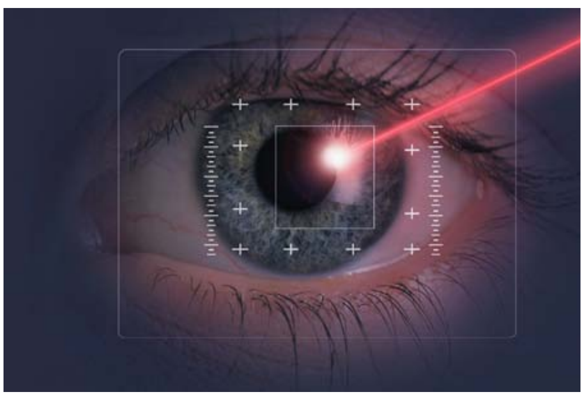
The computing requirements for the next generation of computational researchers will be met by the Blue Waters petascale project at the University of Illinois. Explorations of the capabilities of future technologies are making plans in data intensive computing at the San Diego Supercomputer Center at the University of California at San Diego with the Gordon project, and applications acceleration on innovative hardware at the Georgia Institute of Technology with the Keeneland project. The FutureGrid project led by the University of Indiana is exploring the evolution of grid technologies.

56. Making the Cut

NSF-funded researchers have made significant improvements to surgical interventions including improvements in laser microsurgery and LASIK eye surgery.

In 2001, NSF-funded physicists, along with ophthalmologists at the University of Michigan, made a major improvement in LASIK eye surgery. Prior to their work, a mechanical blade was used to cut the flap of cornea and a laser used to reshape it. Instead, their new method uses a very precise femtosecond laser to create the initial flap. Much more precise than the previous technology, the femtosecond laser improves clinical safety and lessens the chances of uneven cuts or collateral damage. Surgery using this technology is known as IntraLASIK. In 2006, the technology was used for the first time for human corneal transplants. Because of the possibility of increase preciseness, more rapid recovery, and improved post-operative vision, the introduction of the laser for corneal transplants revolutionized the surgery.

Recently, a group of NSF-funded researchers at the University of Texas at Austin made major improvements to microsurgery. In microsurgery, lasers are used to vaporize areas of diseased tissue. Femtosecond duration laser pulses (femtosecond is a millionth of a billionth of a second) can quickly vaporize the target and use less energy while extending surgical precision and reducing surgical complications. The researchers improved this kind of surgery by creating a small probe which uses low-energy femtosecond pulses for two-photon microscopy. This device guides the laser pulses and allows for a maximum field of view with faster imaging speeds. Using the probe, the research group was able to image and ablate breast cancer cells. Unlike previous procedures, this procedure is able to remove an individual cell without harming neighboring cells. This surgical improvement will lead to more surgeries that are able to remove damaged tissue while protecting functioning cells and pathways.



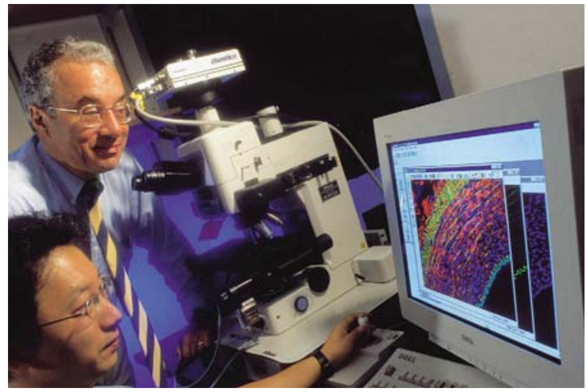
Credit: © 2010 JupiterImages Corporation

Researchers at the NSF Engineering Research Center for Integrated Surgical Systems Technologies, based at Johns Hopkins University, have developed a variety of surgical assistants including a robotic "snake" that finds its way through arteries to sites requiring treatment, where it can perform operations or deliver drugs. Similarly, a "Heartlander" robot is able to move around beneath the pericardium of the heart, under remote control by a surgeon, to perform delicate operations in a minimally invasive manner.

57. Tissue Engineering

The term "tissue engineering" was coined in 1985 by bioengineering pioneer Y.C. Fung of the University of California at San Diego (UCSD). Beginning in 1987, NSF funded a number of workshops and symposia to encourage interest in the field. Tissue engineering has been defined as "the application of principles and methods of engineering and life sciences toward fundamental understanding … and the development of biological substitutes to restore, maintain or improve [human] tissue function." This definition is intended to include procedures where the biological substitutes are cells, or combinations of different cells that may be implanted on a scaffold such as natural collagen, or as synthetic, biocompatible polymers to form a tissue.

Two tissue engineering inventions are now in medical use. These include skin tissue replacement for ulcerations, scaffolds that enable bone tissue to form, and a scaffold that allows the slow release of an anticancer agent to combat a form of brain cancer. NSF-funded research efforts continue with the work for skin replacement, drug delivery and basic studies for understanding the cell-to-tissue process. Tissue engineering includes the use of this technology for other medical applications, such as gene therapy, as well as for the study of how cells interact and communicate.


Credit: Gary Meek, Georgia Institute of Technology

As tissue engineering becomes more of a commercial venture, private industry has become heavily involved, especially with skin replacement, drug delivery and other potential applications. NSF continues, however, to play a central role by supporting important centers of research, such as the Tissue Engineering Centers at the Massachusetts Institute of Technology, the University of Washington and the Georgia Institute of Technology.

NSF recently funded a project that will study engineered tissues that mimic the liver. Since the liver is responsible for vital functions including metabolism and detoxification, deterioration of the liver's functions cause life-threatening illnesses. This research will assemble 3-D cellular structures that mimic the liver to learn more about the liver's structure. This research could lead to breakthroughs in the design of tissue-engineered livers.

58. Cancer and the Cosmos

Surprisingly, astronomers and cancer researchers had a shared problem—they both needed to pinpoint critical spots against a cluttered and perhaps blurred background. Radiologists need to search images for microcalcifications as signs of breast cancer, which are images that are similar to images of a cosmic ray that astronomers study. This shared problem between astronomers and cancer researchers generated new software that allows radiologists greater ability to scrutinize mammograms for signs of breast cancer.


Credit: © 2010 JupiterImages Corporation

This particular link between astronomy and radiology resulted from an NSF grant that allowed astronomers and radiologists from Johns Hopkins University, Georgetown University's Lombardi Cancer Research Center and the Space Telescope to collaborate on using astronomical computer software (originally created to look at highly crowded regions of the sky where millions of stars appeared on a single image) to scan mammograms.

When this software is applied to the examination of mammograms, it essentially removes much of the background clutter in the image and makes it relatively simple to detect microcalcifications, which may be a sign of cancer.

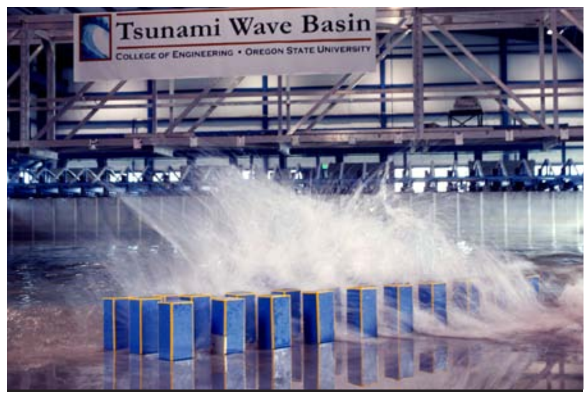
Several studies have shown that digital mammography may be more sensitive at locating breast cancer than film mammography. Digital mammography was developed from research funded by NSF that brought together astronomers and cancer researchers. Digital mammography is believed to control the quality of reading a mammogram in real time and thus helps speed the reading and analysis of mammograms from a few days to the same day the procedure is conducted.

The NSF Engineering Research Center for Subsurface Sensing and Imaging, based at Northeastern University, is using its expertise in the detection of hidden objects to improve the detection of breast and other tumors, resulting in significantly improved images at lower cost.

59. Shaking off the Damage

Several million earthquakes occur worldwide each year, and have caused the death of more than 750,000 people during the past decade, according to the U.S. Geological Survey. To lessen this toll, researchers strive for greater understanding of earthquakes and to seek better ways to reduce the extent of damage from earthquakes.

Significant progress is being made in understanding why earthquakes occur where they do and where future earthquakes may happen. For the first time, the integration of geologic, seismic and geodetic measurements is drawing a consistent picture of the earthquake mechanism that can be used to lessen



Credit: John van de Lindt, Colorado State University (left); College of Engineering, Oregon State University (right)

damage. Engineers have enhanced the reliability and performance of buildings and infrastructure, including homes, bridges, water and electricity lines, and other lifelines on which we rely when an earthquake strikes. They have created novel design approaches, new materials—such as bendable concrete—to withstand seismic forces and better ways to model and analyze risk and structural performance. They have conducted landmark tests on structures ranging from buildings to container cranes, impacting design codes across the U.S.

Many of these ideas were tested at one of the 14 NSF experimental facilities around the nation comprising the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES). These facilities are home to powerful shake tables, a tsunami wave basin and other advanced laboratory and field-testing equipment. Along with sophisticated simulation software, NEES tools are available to researchers on site or through the Internet, allowing them to run simulations and share results with any of the networked sites in real time, from anywhere around the globe.

In 2009, one NEES research project subjected a six-story wood-frame building to a simulated earthquake having motions from the 1994 Northridge, Calif., earthquake, but amplified to a level that equates to an event that occurs, on average, once every 2,500 years. The building survived with no structural damage. The extensive data collected has yielded new insight into the performance of mid-rise wood structures, with significant implications for construction practices wherever earthquakes may occur.

Additionally, three NSF Earthquake Engineering Research Centers (ERC) investigated multidisciplinary aspects of earthquakes. One has focused on reducing losses in the Central and Eastern U.S., where seismic events are infrequent but present significant consequences for the people, economy and civil infrastructure. Another ERC used ground motion data collected over 10 years to develop new ground motion models. Their data was incorporated into the 2008 U.S. National Seismic Hazard Maps, which serve as the basis for design of buildings, lifelines, and other facilities nationwide, and the new information will significantly affect seismic design of most constructed facilities in the entire Western U.S.

60. Volcanic Risk

Volcanoes are the link between the deep earth, the air we breathe and the water we drink, even though eruptions occur irregularly. Volcanic hazards exist on many scales. They can kill, destroy crops and property, and pollute the atmosphere. For all of these reasons, improved understanding of volcanic processes is vital in predicting when these rare events occur so that proper precautions can be taken.

Volcanologists are learning to evaluate physical changes to volcanic domes or edifices as an indicator of impending activity. With improved Earth-based and space-platform technologies, researchers can now measure small changes in temperature and composition of gases escaping from the Earth into the atmosphere, as well as detect minor deformations of volcanic and seismic activity; both indicate magma moving closer to the surface.

Credit: Barry Voight, Penn State

This information has enabled accurate forecasting of explosive events and times of increased hazard, helping to protect scientific fieldworkers and the general public. NSF has funded the development of some of these technologies and their applications to active volcanoes in Hawaii, the western U.S. and Alaska, as well as in the Philippines, Indonesia, the Caribbean and Central and South America.

NSF is also funding research designed to discover new information on magma movement, eruption dynamics and warning signals, lava and ash composition, volcanic emissions and eruption-triggered avalanches and mudflows. The data and improved understanding derived from this research is important for eruption forecasting, monitoring and detection. This new knowledge has also lead to improving hazard assessments in order to reduce volcanic risk to the U.S. and our neighbors abroad.

NSF

Celebrating 60 Years of Discovery