

Statement of

**The Institute of Electrical and Electronics Engineers-
United States of America (IEEE-USA)**

To The

**Subcommittee on Science, Technology, Innovation and Competitiveness
Senate Committee on Commerce, Science and Transportation
United States Senate**

For Inclusion in the Record of a Hearing On

Competitiveness and Basic Research

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The Institute of Electrical and Electronics Engineers-United States of America (IEEE-USA) appreciates this opportunity to share our views on how basic research in the physical sciences impacts both long-term economic development in the United States and the ability of American industry to remain globally competitive.

IEEE-USA strongly supports increased funding for basic research in the physical sciences, mathematics and engineering. IEEE-USA also recommends that Congress and the Executive Branch of the Federal government work with private industry to:

- Maintain healthy and stable basic research investment in science, technology, engineering and mathematics, and provide adequate funding in the federal research portfolio, including a doubling of the investment in basic research;
- Continue to encourage mechanisms for rapid transfer from basic research to technology development to promote U.S. technological competitiveness and innovation, such as the Small Business Innovative Research and Small Business Technology Transfer programs;
- Support graduate students with fellowships and research assistantships, without regard to national origin, to attract, educate and train the best students to serve as the next generation of American engineers and scientists. Such recruitment is crucial to meeting future civilian and defense research needs in conjunction with increased basic research investment in the physical sciences; and

- Increase support for infrastructure, including facilities, instrumentation and equipment.

Basic research provides the foundation for scientific discovery and is vital to advancing technological progress. In the civilian sector, basic research is the critical component to ensure technological competitiveness and innovation. In national security, technological superiority continues to be the cornerstone of our national military strategy.

Federal investment in long-term, high-risk, high-payoff, basic research is particularly important today to maintain the United States' competitive edge in the increasingly competitive global arena. The return on investment (ROI) for basic research is unmatched in its benefit to the economy, the society, and the defense of the United States against its adversaries. Economist Edwin Mansfield calculated the ROI for basic research to be as high as 28 percent. No other federal investment generates a greater long-term return to the economy and society.

Basic research contributes to the quality of life of all Americans by creating jobs, improving the standard of living, and enhancing national security. Products in use every day in America that are a direct result of basic research conducted in the past 40 to 50 years include the Internet, Global Positioning Satellite (GPS) systems, computers, information technology, lasers, magnetic resonance imaging, computerized tomography, and many others.

In addition to the economic benefits in terms of technology and products, federal investment in basic research also provides such benefits as creating high paying jobs. In 2005, high-tech companies in the United States employed more than 5.6 million people and paid an average salary 85 percent higher than average non-technical jobs. Federal basic research creates the critical research infrastructure needed to sustain our global R&D advantage. Research and development are increasingly being conducted in the global marketplace. Recent study indicates that 77 percent of new R&D sites planned over the next three years by private industry will be located in India or China. Federal support for basic research will be indispensable in filling the subsequent void in our research infrastructure.

The importance of basic research is illustrated by the following examples where basic research has led not only to new industries, but also to constructive changes in human society and a better way of life.

Solid State Physics and Materials Science Research

American scientists Walter Brattain, John Bardeen and William Shockley at Bell Lab conducted basic research that led to the discovery of amplification of electricity by a Germanium crystal in 1947, and the invention of the transistor. The invention of the Integrated Circuit (IC) followed this discovery, leading the way to today's complicated circuits on a chip. The number of solid state devices invented snowballed with the introduction of a computer memory chip that can store 1,024 bits of information by Intel Corporation in 1970. In 1977, American inventors Steven Jobs and Stephen Wozniak produced the first personal computer sold as assembled, rather than in kit form. That innovation was unrivaled until the IBM Personal Computer was introduced in 1981, which led to the information technology revolution.

The computer's importance cannot be over-emphasized. Because of computer technology and advances in mathematics, the finite element method was invented -- allowing a designer to build a model in a computer. More importantly, this method allows designers to manipulate the model and quickly see the results. This method is a key part of many advanced engineering systems, including computer-aided design and virtual reality programs. As an example, the Boeing 777 was the first major aircraft designed and eventually built using the finite element method, with extensive computer networking and a computer system including more than 2,200 workstations linked through eight large mainframes.

Life without computers is now unthinkable. The computer impacts our every-day life, both in the office, in our cars, at home, and in commerce. Computers control practically everything in our information and critical infrastructures. The entire computing industry consists of results of a vast research effort at university and industrial laboratories rooted in pure, basic research. The way of science is that one discovery is built on the basis of previous discoveries. The lineage of today's laptop leads straight back to Werner Heisenberg's discovery of quantum mechanics in 1925.

Another example of the fruits of basic research are integrated circuits called Charge-Coupled Devices (CCDs) -- light detectors based on semiconductors, invented and first attached to telescopes to observe the planet Uranus. Being more sensitive than photographic film, the Hubble Telescope, placed into orbit in 1990, uses CCD detectors to examine the universe at high resolution in wave lengths from the ultra-violet to the infrared. Today, these detectors are integral to the commercial digital camera market, and have profoundly changed the art and scope of the science and application of photography.

The Role of Physical Sciences in the Life Sciences

Employing the basic research discoveries of physicist Isidor Isaac Rabi on the magnetic properties of atoms and molecules using nuclear magnetic resonance (NMR), Edward M. Purcell and the Swiss-born, Felix Bloch, separately applied this technique to investigating solids and liquids. In 1971, researchers begin using NMR as magnetic resonance imaging techniques to non-invasively examine internal bodily structures revolutionizing diagnostic medicine.

At the same time, using methods developed by the South African-born American physicist Allan Cormack, X-ray images were manipulated and combined to display the interior of the human body in three dimensions. And Computerized Tomography scans are now vital tools for diagnosing brain and spinal disorders.

The clever use of techniques employed in manufacturing integrated electronic circuits have led to new physical sequencing methods that have accelerated the analysis and sequencing of human DNA leading to the completion of the genetic map (genome). These techniques have also led to successful fabrication of microelectromechanical systems for uses such as measuring blood pressure by the deformation of tiny silicon diaphragms.

Nanotechnology

Richard Feynman said in a classic talk in 1959, “The principles of physics, as far as I can see, do not speak against the possibility of maneuvering things atom by atom. We need to apply at the molecular scale the concept that has demonstrated its effectiveness at the macroscopic scale: making parts go where we want by putting them where we want!” In 1985, American chemists Richard Smalley & Robert Curl, and British chemist Harold Kroto, found that 60 carbon atoms can arrange themselves into molecules shaped like a soccer ball, or a geodesic dome, as designed by Buckminster Fuller. These “buckyballs,” also called fullerenes, provide a flexible base for the design and application of new materials.

Equally dramatic, nanotechnology has the potential to give medicine new instruments to examine tissue in unprecedented detail by fabricating a broad range of complex molecular machines (including, not incidentally, molecular computers). It will enable the fabrication of fleets of computer-controlled molecular tools much smaller than a human cell and built with the accuracy and precision of drug molecules. Such tools will let medicine intervene in a sophisticated and controlled way at the cellular and molecular level to remove obstructions in the circulatory system, kill cancer cells, or take over the function of sub-cellular organelles.

The term nanotechnology encompasses both new science and technology that takes advantage of properties operating at the nanoscale; and engineering molecular machine systems with atomic precision. Many applications of the first type are already appearing today. The second type is what Nobel laureate Richard Feynman outlined in 1959. Controversy exists in the field as to whether the second type is ethical, feasible or over-hyped, but whether research follows the evolutionary or revolutionary approach, the resulting knowledge and applications are apt to be numerous and startling.

Quantum electrodynamics

Basic research in quantum electrodynamics has led to the invention of the laser, (Light Amplification by the Stimulated Emission of Radiation). It was discovered that a laser removes tissue with minimal heating of its surroundings. In 1961, only a year after its invention, a physicist and ophthalmologist employed a ruby laser to destroy a tumor on the retina of a human eye. Laser surgery is now commonplace for corneal sculpting and the removal of cataracts.

NASA and the National Institute of Standards supported basic research in atomic clocks. In 1993, culminating a 20-year project, the U.S. Air Force launched the last of 24 Navstar satellites that carry atomic clocks for use in the Global Positioning Systems (GPS). Today, people anywhere on Earth can determine precise location using GPS for navigation, automobile guidance, hiking and geophysical research. An entire viable commercial enterprise has emerged employing GPS.

Light or photons can transmit, manipulate and store information more efficiently than electrons. Now, optical fibers are beginning to replace the copper wires that have been used for data transmission for more than a century. However, the all-optical computer, with photonic integrated circuits, is still in its infancy. When it matures, revolutionary new ways to make thinking machines will become possible.

Information Technology

Basic research led to the invention of the transistor, integrated circuits, and the computer as discussed above. The nation's information technology (IT) infrastructure has now become a seamless fabric of interconnected computing and storage systems, mobile devices, software, wired and wireless networks, and related technologies. The basic research in computers has led to billions of dollars for the IT industry that is indispensable to public and private sector activities throughout our society and around the globe. Furthermore, basic research in communication technology has led to the development of the cell phone industry, and to the development of pervasive, cost-effective, wireless network communication systems to enable a vast, constant flow of information. IT has transformed the way we work, and processes in government, business, industry, health care and scientific research.

The IT revolution has made it such that our critical infrastructures, such as food, water, energy, finance, transportation, and public health all depend on the IT infrastructure. The interconnected network of information systems made it possible to deliver essential information seamlessly, in case of national disasters or emergencies. It took many years of basic research to lead to where we are today in the IT industry. And many more years of basic research is needed to make sure our IT infrastructures are protected against cyber attacks.

Technology for National Security

Technological superiority is a key element of deterrence, both in war and in peace. Technologies such as radar, jet engines, nuclear weapons, night vision sensors, smart weapons, stealth, GPS, Unmanned Aerial Vehicles, and IT systems for network-centric warfare have changed dramatically the way we fight wars and protect our country. These superior defense technologies are the result of the DOD's investment in basic research in the 1980s and 1990s. Although technological breakthroughs and revolutionary military capabilities are sometimes difficult to predict from investment in basic research, a few examples can demonstrate the full impact of basic research on military capabilities, many years after its initial basic research investment:

- As discussed above, the GPS is a global positioning system that was originally developed to replace the LORAN-C navigation systems for submarines. Developing GPS required basic research in several other disciplines, such as precision atomic clocks. Today, GPS is being used both in defense systems for precision guided munitions and cruise missiles, and in civilian automobiles and other locating devices.
- Development of Infrared Focal Plane Arrays (IRFPA) was based on long-term basic research stemming from the 1950s. Basic theoretical research supported by the Army led to the discovery that bandgap of mercury cadmium telluride could be engineered with sufficient sensitivity to detect natural thermal emissions. This discovery led to the development of IRFPAs are now widely used in missile-seekers, guidance systems and in surveillance systems.
- A well-known and often cited example is the development of the World Wide Web. Originally, DARPA's basic research developed the Internet to allow the universities involved in defense projects to communicate with each other. Today, the Internet is indispensable for the office, government and the home.

- Satellite technology, developed after Russia's Sputnik in 1957, was heavily supported by the Air Force basic research programs. Today, satellites are widely used in telecommunications, navigation, surveillance, and weather observations, including tracking hurricanes.
- Stealth technology has been based on the basic research of Dr. Joseph B. Keller's initial research on how light and radar signals are reflected by objects. Today, stealth technology has enabled our aircraft to enter battle space virtually unobserved by our adversaries.

These technologies and many others have demonstrated the value of long-term, basic research to ensure our technological superiority in the battlefield.

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