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Breaking Moore's Law:
R&D Policy for Emerging Computer Hardware Technologies

by

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This report was submitted to the Institute of Electrical and Electronics Engineers, Inc. (IEEE) to meet the requirements of the Washington Internships for Students of Engineering (WISE) for the Summer 2000 program.

About the Author

James Devaney is a senior in electrical engineering and computer engineering at University of Missouri Columbia. His research interests include digital systems and computer architecture. This paper is the product of research and development conducted through the Washington Internships for Students in Engineering (WISE) program for summer 2000. His internship was sponsored by the Institute for Electrical and Electronics Engineers (IEEE).

About WISE

The Washington Internships for Students in Engineering (WISE) program annually selects fourteen to sixteen outstanding students, entering their final year of undergraduate study, through a nation-wide competition, to spend ten weeks in the summer in Washington, D.C. During the internship they learn how government officials make decisions on complex technological issues and how engineers can contribute to legislative and regulatory public policy decisions. The students interact with leaders in the Congress and the Administration, industry, and prominent non-governmental organizations. Meetings with congressional Committees, executive office departments, and corporate government affairs offices are daily activities.

The internship culminates with a presentation and paper, the student produces, on an important engineering-related public policy issue.

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Executive Summary

Advances in information technology (IT) have fueled the longest economic boom in the United States since the 1850's. The IT revolution has brought on increasing social and economic prosperity. Microchips power the IT revolution and generate enormous contributions that increase our productivity and make our lives healthier and more enjoyable. Powerful computers have increased our quality of life and transformed every aspect of the economy, improving areas from weather forecasting and health care to telecommunications and industrial manufacturing.

IT relies upon semiconductor technology. Semiconductors are the building blocks of microchips and make IT possible. The semiconductor industry contributes more value to the economy than any other industry. IT producers, annually account for over $500 billion of the economy and have increased the value added per by ten percent annually over the past decade.

The primary factor that has fostered the success of information technology, and its tremendous impact on society is the semiconductor industry's ability to continually reduce the size of components on a microchip. Decreasing component size allows more components to fit on a chip thereby decreasing the cost for processing power. In 1965, Gordon Moore, the cofounder of Intel, noted a linear relationship of the rate of increasing component density at reduced cost: Every eighteen months, the component density or capacity of semiconductors doubles. This empirical assertion has become known as Moore's Law and has remained accurate through the present.

Moore's Law has become a critical industry timeline for the development and production of each generation of microchips. Shrinking the size of the components allows the industry to deliver more value to the consumer without additional cost. This almost unprecedented industrial ability is what drives the IT revolution. It is the primary reason for the economic boom we are presently experiencing.

However, microchip components can only be scaled down so far before undesired properties prevent reliable operation. This physical size limitation is rapidly approaching. There is now a consensus among industry experts that within six years, the semiconductor industry will begin to face technical challenges for which there are no known solutions.

When these barriers are reached, the age of silicon may be over. Many industry experts believe this will occur within 10 to15 years. The only solution, at this point, lies in a new hardware technology. Unfortunately, the industry's alarm is compounded because the necessary long term research and development of the replacement technology is not occurring.

The US is the global leader in semiconductor research, design, and manufacturing and there is history of government support for long-term research and development (R&D) in semiconductor technology. Ultimately the solutions, to the problems presently confronting the industry, will come from long-term basic research. Current IT R&D policies are attempting to address the industry's concerns, but a recent report by a congressionally chartered committee concluded that federal IT R&D support is seriously insufficient and too heavily focused on near term problems.

The report let to the Information for the Twenty First Century (IT^2) initiative and ultimately to the H.R. 2086 bill pending before Congress.

The semiconductor industry is very concerned about maintaining the Moore's Law rate of development and conducts its own biannual reviews on the state of semiconductor technology. The results of the most recent evaluation were so alarming that the Semiconductor Industry Association, the leading U.S. semiconductor trade association, is urging increased federal support for university level research. Five actions are called for:

1. Develop a strategy for basic federal R&D funding;
2. Develop partnerships with universities between government and industry;
3. Develop programs that attract more U.S. students to the physical sciences and engineering;
4. Maintain research infrastructure
5. Increase federal support of research funding by passing H.R. 2086, S. 296, and funding the National Nanotechnology Initiative.

In addressing the problems and proposed solutions, several conflicts and concerns arise.

- Can industry afford to fund IT R&D on its own?
- Are we spending enough on long-term R&D?
- Are H.R. 2086 and S. 296 the right solutions?
- Will semiconductor technology level out?
- Are we educating enough future engineers and scientists?

These conflicts and concerns are analyzed in order to determine the best policy solutions.

This paper concludes with the following policy recommendations:

- Pass H.R. 2086 and S. 296 with modified spending levels
- Create a focused long-term IT R&D strategy
- Fund the National Nanotechnology Initiative
- Develop programs that attract more students to Engineering and Physical Sciences

The Issue

Introduction

In 1971 Intel released the *4004*- the worlds first microprocessor. It contained over two thousand transistors and was capable of sixty thousand instructions per second.[1] Today Intel's *Pentium III* contains over eight million transistors and can process over a billion instructions per second.[2] For almost thirty years, the semiconductor industry has provided increasingly powerful microprocessors with decreasing costs. The result of delivering more and more value to the consumer for less cost has enabled the IT revolution and elevated the U.S. economy.

Microprocessor technology has its roots in federally supported basic research. Today this technology is facing a potential crisis. The solutions, to these problems facing the semiconductor industry and ultimately society, lie in long-term basic research.

This paper examines the challenges facing the semiconductor industry. It analyzes the current government and industry policies addressing these problems. It examines the conflicts and concerns about the existing policies and proposed solutions. Finally, it considers key policy alternatives, and makes recommendations.

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[1] Rosch, Winn L. "Intel 4004: Microprocessor Quick Reference." *Hardware Bible Website*. Aug. 1, 2000. <http://hardwarebible.com/Microprocessors/4004.htm>.
[2] Intel Corporation. *Intel Microprocessor Performance Table*. Aug. 1, 2000. <http://san.stanford.edu/~t361/projects/tmctable.html>.

Issue Definition

The significant challenges facing the semiconductor industry threaten ongoing advances in technology. To ensure the continued prosperity, enabled by the IT revolution, several key issues Must be addressed.

- Why should the U.S. government be concerned about the state of present computer hardware technology?
- Does the United States need a national strategy for long-term R&D of future computer hardware technologies?
- Is there sufficient funding for long-term R&D of future computer hardware technologies?

How does this issue concern IEEE?

The Institute of Electrical and Electronic Engineers (IEEE), is the leading professional society for electrical and information technologies and sciences. Its goals include,

> "[Advancing] global prosperity by promoting the engineering process of creating, developing, integrating, sharing, and applying knowledge about electrical and information technologies and sciences for the benefit of humanity and the profession."[3]

In the past, advances in electrical engineering, such as the development of the integrated circuit, have enabled the IT revolution and fostered today's healthy economy. In the future, the development of new computing hardware technologies will have a direct consequence on the IT

[3] Institute of Electronics and Electrical Engineers. *About the IEEE*. Jul. 7, 2000. Aug. 1, 2000. <http://www.ieee.org/about/>.

community, which IEEE represents, and will eventually have an impact on society. The semiconductor industry employs electrical and electronics engineers, and these individuals, working in industry, government laboratories, and universities will solve the problems that the industry is now facing.

IT policies have a direct affect on the electrical engineering community and therefore IEEE. IEEE has advocated some of the policy solutions this paper calls for, including passing the Networking and Information Technology Research and Development Act, passing the Federal Research Investment Act, and developing programs to attract more students to technical fields.

<u>BACKGROUND</u>

What are Semiconductors?

For the purposes of this paper, semiconductors are the fundamental materials from which present computer chips are made.[4]

How has semiconductor technology affected society?

In almost every corner of society we can observe the benefits of semiconductor technology. From our computers to our watches, toasters and coffee makers, its contributions increase our productivity and make our lives healthier and more enjoyable. Movies, radio, televisions, and

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[4] For a more detailed explanation of semiconductors, see the Intel Museum Online:
Intel Corporation. *How a Transistor Works: What is a Semiconductor*. Aug. 1, 2000.
<http://intel.com/education/transworks/flat5.htm>.

telephones are all possible because of semiconductor technology. Microprocessors, based on semiconductors are even used to make our automobiles safer and more efficient.

Computers have revolutionized every aspect of our economy. Telecommunications, industrial manufacturing, meteorology, and medicine have improved. Pharmaceutical companies are able to model new drugs, predict possible side affects, and analyze the results. Weather forecasting has significantly improved as a result of computer forecasting models. Storm tracking, advanced hurricane warning, wind damage analysis, and predicting long term weather trends, such as El Nino, are all made possible by computer simulation and analysis. Industries save time and money using computer automated drawing (CAD) to design new "virtual" components and products, eliminating the need to build many prototypes, and allowing significant design changes to occur much later in the design process. Boeing 's recent 777 was completely designed and simulated on computers before a single weld or rivet.[5] Many potential conflicts were addressed, before becoming serious problems, saving the company millions. According to a 1998 Department of Commerce study, the semiconductor industry is the largest contributing industry to the United States economy in terms of value added. The industry contributes 20 percent more than its nearest rival.[6]

Semiconductors make information technology and the Internet possible. The Internet now reaches more than 80 million homes and workplaces, and its impact on the economy is unprecedented.

[5] Boswell, Bill. "Time To Market." *Oracle Evolving Enterprise*. Vol. 1 (Spring 1998): 6 pars. Aug. 1, 2000. <http://www.lionhrtpub.com/ee/ee-spring98/boswell.html>.
[6] Semiconductor Industry Association. *About SIA*. Aug. 1, 2000. <http://www/semichips.org/about/index.htm>.

> "The Internet has quickly become a significant economic force, offering a new avenue for consumer and business-to-business transactions. The U.S. "Internet economy" grew at a compounded annual rate of 174.5 percent between 1995 and 1998, as compared with 2.8 percent for the national economy as a whole. The Internet economy generated revenues totaling an estimated $301 billion in 1998. Employing more than a million people, the Internet economy now rivals the automobile industry and other major established sectors in size…Direct, business-to-business commerce on the Internet is forecast to surpass $1.3 trillion per year by 2002."[7]

The United States is experiencing the longest economic boom since the 1850s. Federal Reserve Chairman Alan Greenspan has noted, "An economy that 20 years ago seemed to have seen its better days is displaying a remarkable run of economic growth that appears to have its roots in ongoing advances in technology."[8]

The Computing Research Association (CRA), an organization that represents the computing research community, outlines following economic impacts of information technology.

- "IT producers were responsible for *more than one-third of real economic growth* in 1995-98, despite accounting for only 8 percent of GDP;
- IT industries account for more than $500 billion of the annual U.S. economy;
- Falling prices in IT-producing industries reduced overall inflation by an average 0.7 percentage points in 1996-97;
- Average value added per worker in IT-producing industries grew by more than 10 percent annually during 1990-97;"[9]

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[7] United States Office of Science and Technology Policy. President's Information Technology Advisory Committee. *Wellspring of Prosperity: Science and Technology in the U.S. Economy*. Spring 2000. 4.

[8] Bloch, Erich., Dr. Ralph Cavin and Kathleen Kingscott. "The Economy, Federal Research and the Semiconductor Industry." Semiconductor Industry Association. Mar. 8, 2000. 3.

[9] Computing Research Association. "The National Investment in Information Technology R&D." *Policy Brief* Aug. 1, 2000. <http://www.cra.org/govaffairs/advocacy/investment_pb.pdf>.

Big Advantages from Going Small

The primary factor, enabling so many benefits to society, is the semiconductor industry's ability to continually reduce the size of components on a microchip. Shrinking the size of the components, called *scaling*, allows the industry to deliver more value to the consumer, without additional cost. This almost unprecedented industrial accomplishment delivers considerable advantages. Decreasing component size, thereby increasing circuit component density, results in smaller and faster microchips with increased reliability, functionality, and efficiency. At the same time, costs are decreased.[10]

> "By making things smaller, everything gets better simultaneously. We don't even really make a tradeoff. The transistors get faster, the electrons don't have so far to go, the capacitance goes down and one thing and another. Shorter interconnections again speed up the operation of electronics and decrease the power necessary to drive the interconnections. System reliability is increased tremendously because we put a lot more of the system on the chip, which is a controlled environment. And…the system reliability has grown tremendously as we've put more and more electronics on a given chip," (Gordon Moore 1965).[11]

In 1965 the cofounder of Intel, Gordon Moore, noted a linear relationship of the rate of increasing circuit component density at reduced cost. "The complexity for minimum component costs has increased at a rate of roughly a factor of two per year."[12] Ten years later, while delivering a paper at the IEEE meeting for International Electron Device, Moore refined his earlier observation showing, "that circuit density or capacity of semiconductors doubles every

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[10] Glaze, James. "Infinite Riches in a Little Space." *Science and Technology Review* Lawrence Livermore National Laboratory. Nov. 1999.
[11] Intel Corporation. "'An Update on Moore's Law' Intel Chairman Emeritus Gordon Moore." *Speech*. Jul. 26, 2000. <http://www.intel.com/pressroom/archive/speeches/GEM93097.HTM>.
[12] Schaller, Bob. *The Origin, Nature, and Implications of 'Moore's Law': The Benchmark of Progress in Semiconductor Electronics*. Sep. 26, 1996. Jun. 8, 2000. <http://research.microsoft.com/~Gray/Moore_Law.html>. 7

eighteen months"[13] Surprisingly Moore's empirical assertion has held true through the present. Known today as Moore's Law, it has become an industry timeline for the development and production of each generation of microchips (see figure 1).

> "The effect of Moore's Law on daily life is obvious. It is why today's $3,000 personal computer will cost $1,500 next year and be obsolete the year after. It is why the children who grew up playing Pong in game arcades have children who grow up playing Quake on the Internet. It is why the word-processing program that fit on two floppy disks a decade ago now fills up half a CD-ROM—in fact, it explains why floppy disks themselves have almost been replaced by CD-ROMs, CD-Rs and CD-RWs."[14]

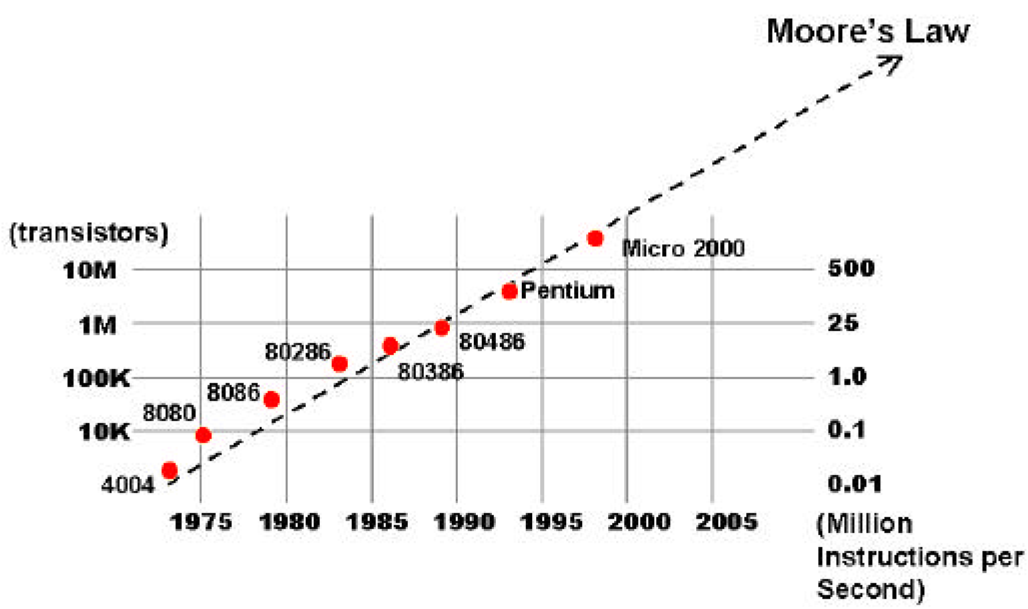

Figure 1. Intel Microchips and Moore's Law

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[13] Schaller, Bob. *The Origin, Nature, and Implications of 'Moore's Law': The Benchmark of Progress in Semiconductor Electronics*. Sep. 26, 1996. Jun. 8, 2000. <http://research.microsoft.com/~Gray/Moore_Law.html>. 8

[14] Mann, Charles C. "The End of Moore's Law?" *Technology Review* (May/June 2000) Jul. 26, 2000. <http://www.techreview.com/articles/may00/mann.htm>.

The impact of semiconductor technology is only beginning. There are still many benefits computers can yield. There are still many problems we face, with solutions that lie in advancing our information technologies.

What will further developing computer technology mean?

Many economists believe the persistent increase in chip power has imparted a fundamental change in the nations economy: a favorable environment of steady growth and low inflation.[15]

> '"What's sometimes called the 'Clinton economic boom,'" says Robert Gordon, an economist at Northwestern University, "is largely a reflection of Moore's Law." In fact, he says, "The recent acceleration in productivity is at least half due to the improvements in computer productivity."'[16]

The present level of computing power has enabled scientists to undertake problems that were once considered unsolvable, and provided increasingly greater levels of economic prosperity. But present computing power remains inadequate for addressing many critical issues facing society. National security, national defense, advanced medicine, and weather monitoring forecasting, all require higher processing power.

Increasing social and economic prosperity

Erik Brynjolfson, an economist at MIT's Sloan School of Management, has explained, "Computers are the most important single technology for improving living standards. As long as Moore's Law continues, we should keep getting better off. It will make our children's lives

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[15] Mann, Charles C. "The End of Moore's Law?" *Technology Review* (May/June 2000) Jul. 26, 2000. <http://www.techreview.com/articles/may00/mann.htm>.
[16] Mann, Charles C. "The End of Moore's Law?" *Technology Review* (May/June 2000) Jul. 26, 2000. <http://www.techreview.com/articles/may00/mann.htm>.

better."[17] The information revolution is just beginning. Its future wields significant benefits to further improve our lives and livelihood. Many new potential applications, capabilities, and ideas emerge each day. The President's Information Technologies Advisory Committee (PITAC) has identified ten critical applications[18] where IT can greatly improve society. These challenges include areas of communications, education, commerce, employment, healthcare, industry, and environment.

Greater processing power will bring smart Internet agents and interfaces between humans and machines. Internet agents will be capable of searching the web for the user and downloading all the needed information and *only* the needed information. They will be capable of determining the users likes and dislikes and of making suggestions to the user.

There is an increasing need for computer systems that handle vast amounts of data.
Making long-term weather forecasts, increasing warning times for severe weather, modeling complex proteins for new drugs, and other simulations are all processes that require high rates of data processing. With the increase of available information, and the development and proliferation of information acquiring technologies such as sensors, computer systems capable of processing large amounts of information are needed.

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[17] Mann, Charles C. "The End of Moore's Law?" *Technology Review* (May/June 2000) Jul. 26, 2000. <http://www.techreview.com/articles/may00/mann.htm>.

[18] United States Office of Science and Technology Policy. President's Information Technology Advisory Committee. *Information Technology Research: Investing in Our Future*. Feb. 1999. Jun. 8, 2000. <http://www.hpcc.gov/ac/report/pitac_report.pdf >. 18-19.

Protecting our future

Through computer simulations, scientists can acquire data about experiments that are too dangerous, or expensive to do in the real world. Advanced computer architectures capable of simulating complex scenarios, and generating 3 dimensional models of results are presently being developed. The present political climate discourages the underground testing of nuclear weapons.[19] Advanced high end computing, developed by IBM for the Department of Energy's Accelerated Strategic Computing (ASCI) program, will enable the DOE to *simulate* the explosion of nuclear weapons[20], allowing our stockpile of weapons to be more safely maintained, while eliminating risk and harm to the environment.

Similar computing architectures can be used to simulate the outcomes of catastrophic events in order to evaluate the preparedness of response teams, minimize damages, and locate possible problems before they cause harm. Automobile designs can be run through simulated crash tests, and buildings can be simulated for structural integrity in the event of an earthquake. Modeling and predicting hurricane or other weather catastrophes, the outbreak of disease, and behavior of fires are all examples of areas that will benefit as a result of simulation technology based on advanced computer architectures.

One, potentially powerful computing hardware architecture on the distant horizon, is quantum based computing. Quantum computers can be used to rapidly solve problems that would take the

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[19] Peña, Frederico. Secretary of Energy. "Testimony before the Appropriations Subcommittee on Energy and Water, United States Senate." Oct. 29, 1997. Jul. 26, 2000. <http://www.state.gov/www/global/arms/testimonies/pena/pena.html>.

[20] "New Day Dawns in Supercomputing." *Science and Technology Review* Lawrence Livermore National Laboratory. Jun. 2000.

fastest computers ever developed an infinite number of years to solve.[21] Already in its very early stages of development, quantum computing promises revolutionary breakthroughs in cryptography. Whereas present day computer architectures store information in bits as a "1" OR "0", a quantum computer will store information in bits as a "1" AND "0". This is because of the "laws of super-position of electron mechanics."[22] The implications for code-breaking and data protection are enormous.[23] It may take the fastest modern super computer years to break 128-bit encryption, a standard used today. But cracking the code on a quantum computer, because a quantum bit (called a qubit) exists as both 0 and 1 simultaneously, will be instantaneous.

The concern about the future of semiconductor technology

As the technology grows to meet these challenges, there is rising apprehension about the future of semiconductors. The industries quest for smaller and smaller components as yielded tremendous economic and social improvements, but this quest cannot continue indefinitely. Achieving each new generation of microchips has meant overcoming new technical challenges. For more than twenty years, industry experts have been predicting death of the semiconductor technology. Yet the industry has persisted through creative solutions, and the technology continues to improve. Now however, there is a consensus, among the industry, that the future development of semiconductor technology is in jeopardy. Critical economic and technical

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[21] Kaku, Michio. *Visions: How Science Will Revolutionize the 21st* Century. Anchor Books. New York. 1997. 111.

[22] For additional information about quantum computing, see Grover.
Grover, Lov K. "Quantum Computing: How the Weird Logic of the Subatomic World could Make It Possible for Machines To Calculate Millions of Times Faster Than They Do Today." *The Sciences* (July/August 1999): 24-30. Jul. 26, 2000. <http://cryptome.org/qc-grover.htm>.

[23] Kaku, Michio. *Visions: How Science Will Revolutionize the 21st* Century. Anchor Books. New York. 1997. 110.

barriers are at the horizon. "For the first time, it is the conclusion of industry experts that within six years the semiconductor industry faces technical challenges for which there are no known solutions."[24]

Squeezing existing manufacturing technology

Semiconductors are manufactured using a process called optical lithography. For thirty years, advances in this process have allowed microchip components to continue shrinking and the industry to follow Moore's law. But in recent years, the development of lithographic and other manufacturing technologies has come at a greater cost. Because the minimum component feature size, on a microchip, is determined by the wavelength of light,[25] obtaining smaller features requires shorter wavelengths. Optical lithography can no longer provide the resolution needed for the next generation of microchips. Thus, further increases in device complexity will require the use of newer manufacturing technologies.

Presently, several new types of lithography are being considered by the industry. These may extend the life of present technology another five to ten years. But the increased cost of developing these manufacturing technologies may have considerable effect on the market, and as their limits are approached, the cost of obtaining higher levels of performance sharply rises. This

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[24] Bloch, Erich., Dr. Ralph Cavin and Kathleen Kingscott. "The Economy, Federal Research and the Semiconductor Industry." Semiconductor Industry Association. Mar. 8, 2000. 8.

[25] Known as Rayleigh's resolution limit; see Hutcheson page 3.
Hutcheson G. Dan and Jerry D. Hutcheson. "Technology and Economics in the Semiconductor Industry." *Scientific American* October 1999. Jun. 8, 2000.
<http://www.sciam.com/specialissues/1097/solidstate/1097hutch.html>.

relationship has been labeled *Moore's Second Law*, after Gordon Moore, cofounder of Intel, noted that, "Capital costs [for semiconductor companies] are rising faster than revenue."[26]

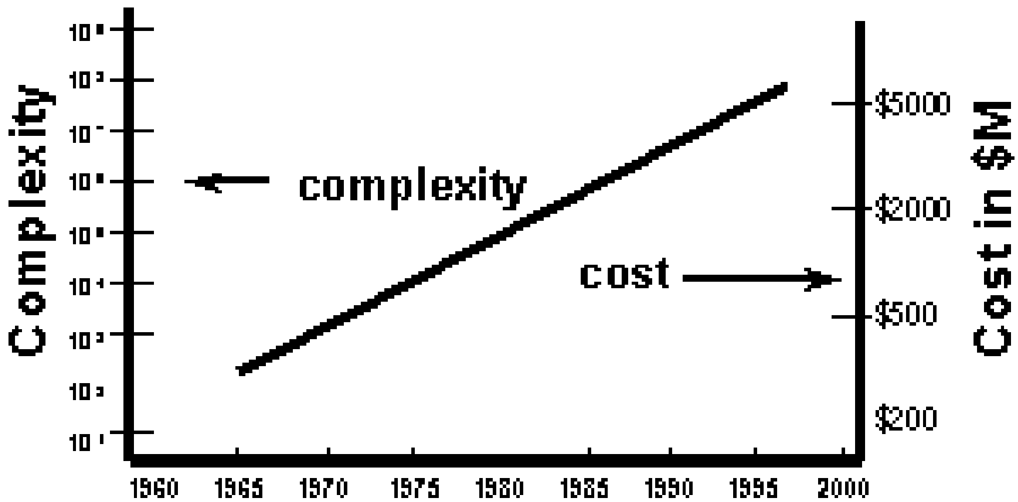

Figure 2. Moore's Second Law

Greater problems on the horizon

In addition to these near-term manufacturing challenges, the semiconductor industry and information technology face even greater problems. Microchip components can only be scaled down so far before undesired properties prevent reliable operation. This physical size limitation is rapidly approaching. The width of the gate oxide insulating material will soon reach four atoms.[27] At such narrow widths, quantum mechanical effects begin to appear. Electrons cease behaving in a predictable fashion and become susceptible to tunneling. As smaller chip components are sought after, there remains no means of reducing statistical variation in the

[26] Mann, Charles C. "The End of Moore's Law?" Technology Review (May/June 2000) Jul. 26, 2000. <http://www.techreview.com/articles/may00/mann.htm>.

distribution of dopant atoms. Additionally, no dopant atoms have been found that maintain higher concentrations of mobile charge density.[28] A report commissioned by the Semiconductor Industry Association stated the following:

> "History teaches us that it will now be difficult to sustain the Moore's Law cadence, even if solutions were available from research today. Integrated circuit performance is increasingly dependent on the physics of material interfaces between atomic scale films rather than on bulk material properties, and increasingly dependent on the precise positioning of atoms rather than on the statistical properties of their distributions."[29]

Unlike the manufacturing challenges, which will likely be overcome with clever fixes, these problems are inherent to present semiconductor technology. Paul A. Packman, an executive at Intel writes, "These fundamental issues have not previously limited the scaling of transistors and represent a considerable challenge for the semiconductor industry. There are currently no known solutions to these problems."[30]

The End of Silicon?

When these barriers are reached, the age of silicon may be over. Many industry experts believe this will occur within fifteen years. The only solution, at this point, lies in a new hardware technology. Unfortunately, the industry's alarm is compounded because the necessary long term research and development of the replacement technology is not occurring. The Semiconductor Industry Association reports that the science base for this new technology is weak, there has been

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[27] Packan, Paul A. "Pushing the Limits." *Science* Vol. 285. Sep. 24, 1999. 2080.
[28] For a more detailed explanation see Packan page 2080.
Packan, Paul A. "Pushing the Limits." *Science* Vol. 285. Sep. 24, 1999. 2080.
[29] Bloch, Erich., Dr. Ralph Cavin and Kathleen Kingscott. "The Economy, Federal Research and the Semiconductor Industry." Semiconductor Industry Association. Mar. 8, 2000. 8.
[30] Packan, Paul A. "Pushing the Limits." *Science* Vol. 285. Sep. 24, 1999. 2081.

marked decline in federal research support, and there is an inadequate supply of skilled scientists and engineers to address these problems.[31] Packan writes, "To continue the performance trends of the past 20 years and maintain Moore's law of improvement will be the most difficult challenge the semiconductor industry has ever faced"[32]

Who are the major players?

Congress

Congress controls all government funding. It has the authority to authorize new programs and serves as an oversight agency. Funding for information technologies primarily falls under three of the thirteen appropriations subcommittees. These are:

- **Veterans Affairs and Housing and Urban Development (VA-HUD)**, which includes the National Science Foundation (NSF);
- **Energy-Water**, which includes the Department of Energy (DOE);
- **Defense**, which includes the Department of Defense (DOD) and the National Security Agency (NSA);

There are also two standing Congressional committees that are responsible for information technology policy, the House Science Committee and the Senate Commerce, Science, And Transportation Committee. Through studies, hearings,

[31] Bloch, Erich., Dr. Ralph Cavin and Kathleen Kingscott. "The Economy, Federal Research and the Semiconductor Industry." Semiconductor Industry Association. Mar. 8, 2000.

forums, and reports, these committees arrive at conclusions about which information technology policies should be adopted.

Executive Office

The Office of Science and Technology Policy (OSTP), one of thirteen offices and agencies responsible for developing and implementing the president's agenda, manages information technology policy. Under the OSTP, is the National Science and Technology Council (NSTC) and below this, the Committee on Technology (CT). The CT supports the NSTC in increasing the effectiveness and productivity of federal R&D for technology.

Another organization directly under the OSTP is the National Coordination Office for Computing, Information, and Communications (NCO/CIC). The NCO is responsible for coordinating federal multiagency research and development for information technologies. The NCO coordinates several programs for IT research and development and works with the IWG on R&D. The NCO also coordinates several programs for IT research and development through the IWG R&D. Two of these programs are the Information Technology for the Twenty First Century (IT^2) Initiative and the High Performance Computing and Communications (HPCC) program.

The High Performance Computing Act (HPCA) in 1991 authorized the HPCC program.

[32] Packan, Paul A. "Pushing the Limits." *Science* Vol. 285. Sep. 24, 1999. 2081.

In 1996, the HPCC program was renamed the Computing, Information, and Communications R&D program (CIC R&D). According to the Congressional Research Service, the name change is meant to, "reflect a new era of federal high-performance computing support," with new priorities of the HPCC programs and new directions in federal policy.[33] Unlike the HPCC Initiative, CIC R&D does not have a congressional authorization. The CIC R&D program has the same goals of the HPCC Initiative. Many of the programs under the HPCC are continuing through the CIC R&D program, thus, they may be referred to as HPCC/CIC R&D programs. Congress continues to fund many of these programs, through the federal agencies that participate in them.

The HPCC/CIC programs are organized into the following five Program Component Areas (PCAs).[34]

- High End Computing and Communications (HECC)
- Large Scale Networking (LSN)
- High Confidence Systems (HCS)
- Human Centered Systems (HuCS)
- Education, Training, and Human Resources (ETHR)

[33] Congressional Research Service Report:
McLoughlin, Glenn J. "Computing, Information, and Communications R&D: Issues in High-Performance Computing." *Congressional Research Service Report for Congress* Congressional Research Service. Library of Congress. Mar. 25, 1997. CRS-1.
[34] United States Office of Science and Technology Policy. Interagency Working Group on Information Technology Research and Development. "High Performance Computing and Communications: FY 1999-FY 2000 Implementation Plan." Apr. 2000. Jun. 8, 2000. < http://www.hpcc.gov/pubs/imp99/ip99-00.pdf>. 1-4.

High End Computing and Communications (HECC) is the Program Component Area (PCA) responsible for the development of next generation computer technologies. The HECC Working Group (HECCWG) coordinates these projects.

The HPCA also chartered a committee, the President's Information Technology Advisory Committee (PITAC), to advise the president about important issues of information technology. PITAC's role was expanded, through the Next Generation Internet Research Act of 1998, to, "assess the extent for which Federal support of fundamental research in computing is sufficient to maintain the Nation's critical leadership in this field," and to make recommendations to the President and Congress.[35]

PITAC is composed of 26 members including, "corporate leaders from the computing and communications industry, two recipients of the National Medal of Technology, and experts from the research, education, and library communities."[36] The committee is co-chaired by Ken Kennedy, Director of the Center for Research on Parallel Computation and Professor of Computational Engineering at Rice University, and Bill Joy, co-founder and Vice President for Research at Sun Microsystems.[37]

[35] Next Generation Internet Research Act of 1998. (P.L. 105-305)
[36] United States Office of Science and Technology Policy. "Interim Report on Information Technology: Questions and Answers." August 10, 1998. Jun. 6, 2000. <http://www.whitehouse.gov/WH/EOP/OSTP/html/presstest/19980810_3.html>. 1.
[37] United States Office of Science and Technology Policy. "Interim Report on Information Technology: Questions and Answers." August 10, 1998. Jun. 6, 2000. <http://www.whitehouse.gov/WH/EOP/OSTP/html/presstest/19980810_3.html>. 1.

Federal Agencies

Ten agencies are involved in federal research and development programs for all areas of IT. However, only nine participate in the HECC program. These agencies are:

- National Science Foundation (NSF)
- National Space and Aeronautics Administration (NASA)
- Defense Advanced Special Projects Agency (DARPA)
- Department of Energy (DOE)
- National Institutes of Health (NIH)
- National Security Agency (NSA)
- National Institute of standards and Technology (NIST)
- National Oceanic and Atmospheric Administration (NOAA)
- Environmental Protection Agency (EPA)

Private Industries

There are approximately six hundred companies worldwide that manufacture semiconductors.[38] Most of these are small industries that only fabricate microchips designed for specific functions and give little attention to semiconductor research. There are approximately fifty United States based companies take an active role in shaping industry guidelines and public policy.[39] These include companies such as Hewlett-Packard, IBM, Intel, Motorola, National Semiconductor, and Texas Instruments.

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[38] Anidigi Integrated Ltd. "Semiconductor Makers: Index" Jul. 19, 2000.Jul. 26, 2000. <http://home.netvigator.com/%7Eanadigi/semi%2Durl.htm>.
[39] Semiconductor Industry Association. *SIA Membership*. Aug. 1, 2000. <http://www/semichips.org/membership>.

Industry Associations and Societies

- **International SEMATECH**

Formerly SEMATECH (**SEM**iconductor **MA**nufacturing **TECH**nology), International SEMATECH (IS) is one of the largest research consortiums in the industry. Seven of the largest semiconductor companies make up IS. These companies cooperate in a pre-competitive research environment that focuses on critical areas of semiconductor technology. Their goal is to develop the advanced manufacturing technologies needed to build tomorrows semiconductors.[40]

- **Semiconductor Industry Association**

The Semiconductor Industry Association (SIA) is the computer chip industry's primary trade association. SIA mission is to, "provide leadership for U.S. chip manufacturers on the critical issues of trade, technology, environmental protection and worker safety and health."[41]

SIA's objectives include maintaining U.S. leadership in technology.

- **Semiconductor Research Corporation**

The Semiconductor Research Corporation (SRC) was established in 1982 by the SIA to "develop a pre-competitive, cooperative research program in the U.S.

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[40] International SEMATECH. *Corporate Information*. Aug. 1, 2000. <http://www.sematech.org/public/corporate/index.htm#memberlist>.

[41] Semiconductor Industry Association. *About SIA*. Aug. 1, 2000. <http://www/semichips.org/about/index.htm>.

university system that is responsive to the needs of the semiconductor industry."[42] It is now the worlds leading university research management consortium. SRC objectives include:

- "Coordinating the identification, analysis, and reporting of key semiconductor R&D issues;
- Creating forums for exchanging views, and developing positions on industry, academia, and government R&D initiatives;
- Determining the shortfalls in semiconductor research funding;
- Encouraging federal and state government leveraged funding support of key research programs;"[43]

- **Institute of Electrical and Electronic Engineers**

The Institute for Electrical and Electronic Engineers (IEEE) is the leading professional society for electrical and information technologies and sciences. Through its publications, conferences, and membership societies, IEEE seeks to, "advance global prosperity by promoting the engineering process of creating, developing, integrating, sharing, and applying [electrical and information sciences and technologies] for the benefit of humanity and the profession."[44] IEEE also promotes public policy that benefits its members, information technologies, and society.

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[42] Bloch, Erich., Dr. Ralph Cavin and Kathleen Kingscott. "The Economy, Federal Research and the Semiconductor Industry." Semiconductor Industry Association. Mar. 8, 2000. 16.

[43] Semiconductor Research Corporation. *SRC Vision, Mission, Character, and Values.* Sep. 1, 1999. Aug. 1, 2000. <http://www.src.org/about/mission.dgw>.

[44] Institute of Electronics and Electrical Engineers. *About the IEEE*. Jul. 24, 2000. Aug. 1, 2000. <http://www.ieee.org/about/>.

- **Computing Research Association**

  The Computing Research Association (CRA) is comprised of over 180 North American academic departments of computer science and computer engineering, their affiliated professional societies, and laboratories and centers in industry, academia, and government engaging in basic computing research. CRA's missions include educating the research community, the public, and government about the state of computing research and policy, increasing the computing communities participation in and awareness of policy issues, and influencing computing research and technology policy.[45]

Academic and Research Community

This includes all universities and national labs working on information technology research that focuses on computer systems architecture, theory of computing, and other areas relevant to next generation computer hardware architectures

Current Policy

How are the problems being addressed?

By The Executive Office

Government organized research for next generation computer hardware technologies occurs through two Subcommittees of the Committee on Technology (CT), the Interagency Working

Group on R&D (IWG on R&D)[46] and to a lesser extent, the Interagency Working Group on Nanotechnology (IWGN). The IWG on R&D includes the National Coordination Office for Computing, Information, and Communications (NCO/CIC). The NCO/CIC and the IWGN contain the initiatives responsible for research and development of the next generation of computer hardware architectures. The NCO/CIC includes the HPCC/CIC R&D programs.

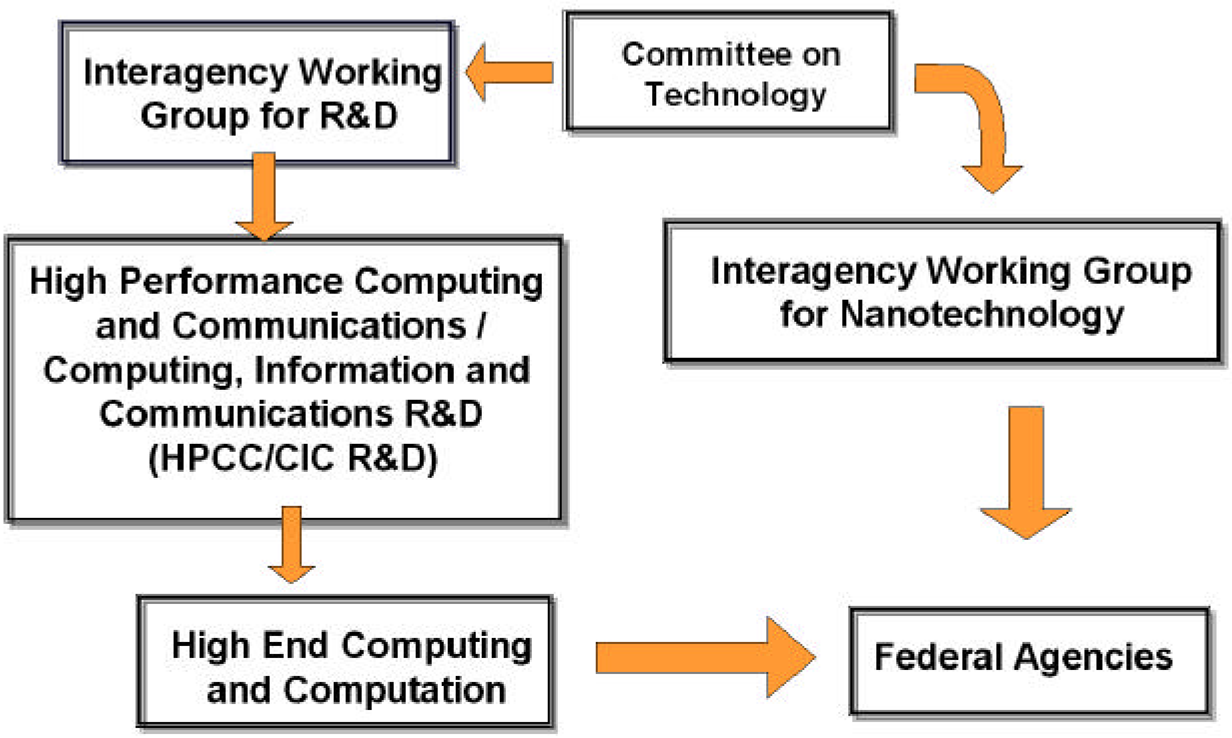

Figure 3. Organization for R&D in Computing Hardware Technologies

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[45] Computing Research Association. *Computing Research Association*. Apr. 11, 2000. Aug. 1, 2000. <http://www.cra.org>.

[46] Prior to FY2000, this was coordinated through the Subcommittee on Computing, Information, and Communications R&D, one of seven subcommittees under the Committee on Technology. Beginning FY2000, CIC is coordinated by the Interagency Working Group on Research and Development (IWG on R&D).

- **HPCC/CIC R&D Program**

The HPCC/CIC R&D program operates with the following goals:[47]

  - "Extend U.S. technological leadership in high performance computing and computer communications;
  - Provide wide dissemination and application of these technologies to speed the pace of innovation and improve national economic competitiveness, national security, education, health care, and the environment;
  - Provide key enabling technologies for the National Information Infrastructure (NII) and demonstrate select NII applications;"

One of the five Program Component Areas of the HPCC/CIC is High End Computing and Communication (HECC). HECC's goal is to establish the foundation for U.S. leadership in Computing through investments in systems hardware and software innovations, algorithms and software for modeling, and simulation for computation-intensive and information-intensive science and engineering applications. HECC also supports the infrastructure needed to carry out the R&D.[48]

To fulfill its goal, HECC is divided into four "thrust" areas:[49]

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[47] United States Office of Science and Technology Policy. Interagency Working Group on Information Technology Research and Development. "High Performance Computing and Communications: FY 1999-FY 2000 Implementation Plan." Apr. 2000. Jun. 8, 2000. < http://www.hpcc.gov/pubs/imp99/ip99-00.pdf>. I.

[48] United States Office of Science and Technology Policy. Interagency Working Group on Information Technology Research and Development. "High Performance Computing and Communications: FY 1999-FY 2000 Implementation Plan." Apr. 2000. Jun. 8, 2000. < http://www.hpcc.gov/pubs/imp99/ip99-00.pdf>. 2.

[49] United States Office of Science and Technology Policy. Interagency Working Group on

- System Software Technologies;
- Leading-edge Research for Future Generations of Computing;
- Incorporation of Technology into Real Applications;
- Infrastructure for Research in HECC;

Leading Edge Research for Future Generations of Computing is the key HECC area that addresses the critical problems outlined earlier. Recognizing the importance of developing next generation computer hardware technologies has only come about recently. "[Within the HECC] there has been a new emphasis on research on fundamental computing technologies based on quantum, optical, and biological phenomena."[50]

Nine Agencies participate in the HECC component of HPCC/CIC R&D. Only four of these agencies are actively involved leading edge research for future generations of computer hardware architectures. The NSF, DARPA, DOE, and NSA all have programs of Leading Edge Research for Future Generations of Computing. Although the other five agencies are involved in HECC, their programs do not directly address the research and development of next generation computer hardware architectures.[51]

Information Technology Research and Development. "High Performance Computing and Communications: FY 1999-FY 2000 Implementation Plan." Apr. 2000. Jun. 8, 2000. < http://www.hpcc.gov/pubs/imp99/ip99-00.pdf>. 15-17.

[50] United States Office of Science and Technology Policy. Interagency Working Group on Information Technology Research and Development. "High Performance Computing and Communications: FY 1999-FY 2000 Implementation Plan." Apr. 2000. Jun. 8, 2000. < http://www.hpcc.gov/pubs/imp99/ip99-00.pdf>. 2.

[51] For a detailed look at each agencies programs in HPCC, see pages 58-213.
United States Office of Science and Technology Policy. Interagency Working Group on Information Technology Research and Development. "High Performance Computing and Communications: FY 1999-FY 2000 Implementation Plan." Apr. 2000. Jun. 8, 2000. < http://www.hpcc.gov/pubs/imp99/ip99-00.pdf>. 58-213.

Despite no longer having congressionally authorization, the HPCC/CIC R&D program continues to be funded by Congress. Requested funding for the program in FY 1999 was $846 million.[52] The HECC component requested $517 million, which is over sixty percent of the total funding requested for HPCC/CIC. Again in FY 2000, almost sixty percent of the requested HPCC/CIC budget is for HECC. Proposed budget for HPCC in FY 2000 is 1.462 billion.[53]

- **President's Information Technology Advisory Council**

The President's Information Technology Advisory Council (PITAC), charged by congress to assess the federal governments support in fundamental computing research, issued its final report in February 1999. PITAC arrived at its conclusions through public meetings, briefings by experts in computing and communications from the federal and private sector, and evaluating all federal research programs to support the development of advanced information technology.

The PITAC report observed that, "critical problems are going unsolved, and the rate of flow of new ideas is dangerously low,"[54] and concluded the following:[55]

- **Federal information technology R&D investment is seriously inadequate.**

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[52] United States Office of Science and Technology Policy. Interagency Working Group on Information Technology Research and Development. "High Performance Computing and Communications: FY 1999-FY 2000 Implementation Plan." Apr. 2000. Jun. 8, 2000. < http://www.hpcc.gov/pubs/imp99/ip99-00.pdf>. 13.

[53] United States Office of Science and Technology Policy. National Science and Technology Council. "Information Technology for the Twenty-First Century: A Bold Investment In America's Future." Jun. 1999. Jun. 8, 2000. < http://www.hpcc.gov/pubs/it2-ip/it2-ip.pdf>. 2.

[54] Computing Research Association. "The National Investment in Information Technology R&D." *Policy Brief* Aug. 1, 2000. <http://www.cra.org/govaffairs/advocacy/investment_pb.pdf>.

[55] United States Office of Science and Technology Policy. President's Information Technology Advisory Committee. "Information Technology Research: Investing in Our Future." Feb. 1999. Jun. 8, 2000. <http://www.hpcc.gov/ac/report/pitac_report.pdf >. 21-23.

- **Federal information technology R&D is too heavily focused on near-term problems.**

The report also recommended the ***creation of a strategic initiative in long-term information technology R&D.*** The new initiative should support long-term research in fundamental issues in computing, information, and communications and should increase the total IT R&D funding base by $1.37 billion through 2004. With increased funding, participating federal agencies should embark on high-risk and "visionary" research.[56]

Four areas of the IT research area agenda are identified as needing priority attention to help the U.S. meet important national defense and economic needs and maintain its position as the global leader in IT:[57]

- Software
- Scalable Information Infrastructure
- High End Computing
- Socioeconomic Impact

Each of these priorities is further broken down in to specific aspects that need increased funding and attention. High End Computing (HEC) is divided into five components including research

[56] United States Office of Science and Technology Policy. President's Information Technology Advisory Committee. "Information Technology Research: Investing in Our Future." Feb. 1999. Jun. 8, 2000. <http://www.hpcc.gov/ac/report/pitac_report.pdf >. 24.

[57] United States Office of Science and Technology Policy. "Interim Report on Information Technology: Questions and Answers." Aug. 10, 1998. Jun. 6, 2000. <http://www.whitehouse.gov/WH/EOP/OSTP/html/presstest/19980810_3.html >. 3.

into innovative computing technologies and architectures. PITAC concluded that present research in this area is significantly under funded.

> "To ensure that U.S. scientists continue to have access to computers of the highest possible power, funding should be focused on innovative architectures, hardware technologies, and software strategies that overcome the limits of today's systems. Without major increases in funding in these areas, the realizable performance of new machines will fall far short of their potential."[58]

PITAC also recommended that the HECC working group be expanded to include all major elements of the government's investment in HEC.[59]

- **Information Technology for the Twenty First Century Initiative**

With the PITAC reports conclusion that federal investment in IT R&D is inadequate, the Administration proposed major increases in IT R&D and a new initiative was created. The Information Technology for the Twenty First Century (IT^2) initiative responds directly to the findings and recommendations of PITAC[60]

> "The IT^2 focuses explicitly on long-term, fundamental research to address the under investments noted by the PITAC in its report. When added to existing HPCC investments, new funding through IT^2 will provide a necessary first step in restoring the imbalance between fundamental research and development and shorter-term, mission oriented research and development in the current Federal portfolio."[61]

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58 United States Office of Science and Technology Policy. President's Information Technology Advisory Committee. "Information Technology Research: Investing in Our Future." Feb. 1999. Jun. 8, 2000. <http://www.hpcc.gov/ac/report/pitac_report.pdf >. 4-5.

59 United States Office of Science and Technology Policy. President's Information Technology Advisory Committee. "Information Technology Research: Investing in Our Future." Feb. 1999. Jun. 8, 2000. <http://www.hpcc.gov/ac/report/pitac_report.pdf >. 5.

60 United States Office of Science and Technology Policy. National Science and Technology Council. "Information Technology for the Twenty-First Century: A Bold Investment In America's Future." Jun. 1999. Jun. 8, 2000. < http://www.hpcc.gov/pubs/it2-ip/it2-ip.pdf>. 2-3.

61 United States Office of Science and Technology Policy. National Science and Technology Council. "Information Technology for the Twenty-First Century: A Bold Investment In America's Future." Jun. 1999. Jun. 8, 2000. < http://www.hpcc.gov/pubs/it2-ip/it2-ip.pdf>. 2.

IT^2 extends existing IT research through HPCC/CIC R&D and provides an opportunity to address new areas such as, "Long term information technology research and development leading to fundamental advances in computing and communications."[62] The proposal budgets $366 million for increased investments in CIC R&D to, "expand the knowledge base in fundamental information science, advance the Nation's capabilities in cutting edge research, and train the next generation of researchers…"[63] This requested funding is in addition to the base funding of HPCC /CIC R&D. IT^2 relies upon existing programs under HPCC/CIC R&D and assumes they will continue to be maintained. If the IT^2 initiative receives congressional authorization, it will be managed, by the IWG on R&D, together with the HPCC/CIC R&D program in order to increase research efficiency. Additionally, the initiative is to be annually reviewed by PITAC.

- **National Nanotechnology Initiative**

The National Nanotechnology Initiative (NNI) is a proposal that creates federal support for, long-term nanoscale research and development that may lead to many potential breakthroughs in areas including nanoelectronics, and computation and information technology.[64] Nanotechnology is the fabrication of devices with atomic or molecular scale (10^{-9} meters)

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62 United States Office of Science and Technology Policy. National Science and Technology Council. "Information Technology for the Twenty-First Century: A Bold Investment In America's Future." Jun. 1999. Jun. 8, 2000. < http://www.hpcc.gov/pubs/it2-ip/it2-ip.pdf>. 2.

63 United States Office of Science and Technology Policy. National Science and Technology Council. "Information Technology for the Twenty-First Century: A Bold Investment In America's Future." Jun. 1999. Jun. 8, 2000. < http://www.hpcc.gov/pubs/it2-ip/it2-ip.pdf>. 1.

64 United States Office of Science and Technology Policy. National Science and Technology Council. "National Nanotechnology Initiative: Leading to the Next Industrial Revolution." February 2000. Jun. 6, 2000. < http://www.nano.gov/nni.pdf>. 14.

precision.[65] Nanoelectronics holds promising hope for the semiconductor industry. Nanostructured devices and fabrication methods have the potential to solve the challenges the industry faces. Research funded through the NNI may generate breakthroughs such as, "nanostructured microprocessor devices that continue the trend in lower energy use and cost per [transistor]."[66]

The estimated current level of federal support for nanotechnology research for FY 2000 is $270 million. An additional $255 million in support for FY 2001 is proposed by the initiative. The initiative is managed through the Interagency Working Group for Nanotechnology (IWGN), a The IWGN coordinates all federal agency activities in the NNI.

By Congress

Through the House Science Committee, and the Senate Committee on Commerce, Science, and Transportation, congress holds hearings and solicits expert testimony to determine what areas of IT R&D are priorities, what areas need federal attention, and what areas are important for the U.S. to maintain a strong leadership position in IT. In a congressional hearing before the Subcommittee on Basic Research Committee on Science, Dr. Neal Lane, Assistant to the President Science and Technology, testified about the importance of, "Laying a Foundation for the Future." Based on the findings of PITAC, the Administration has significant increase in support for several key areas including,

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[65] About.com *Introduction to Nanotechnology* Jul. 26, 2000. <http://nanotech.about.com/science/nanotech/library/blintro.htm>.

[66] United States Office of Science and Technology Policy. National Science and Technology Council. "National Nanotechnology Initiative: Leading to the Next Industrial Revolution." February 2000. Jun. 6, 2000. < http://www.nano.gov/nni.pdf>. 17.

> "Entirely new approaches to the design of computers needed to ensure that computational power continues to increase even when we begin to approach the limits of how small we can make electronic components. This will include exploring exotic tools such as quantum computing or using DNA or other chemicals for processing data."[67]

Several key legislative efforts have addressed IT R&D. Congress authorized the High Performance Computing Act in 1991. Although the initiative has officially expired, the programs it has created continue to receive funding. Congress is presently considering legislation that addresses many of the concerns outlined by PITAC. The Networking and Information Technology Research and Development (NITRD) proposal (H.R. 2086) is a bill that increases federal funding for long-term research and development in information technologies.[68] H.R. 2086 amends the High Performance Computing Act by authorizing appropriations for FY 2000 through 2004 for research and development activities within the HPCC. It is the congressional answer to the IT^2 initiative proposal.

H.R.2086 extends the life of PITAC, requiring the committee to report its findings and recommendations to Congress every two years. H.R. 2086 also establishes a permanent the research and experimentation tax credit. This gives the semiconductor industry greater opportunity for solving the daunting challenges it faces. The bill had unanimous bipartisan support from the House Science Committee. The House has passed it, and it is presently in Senate committee.

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[67] Lane, Neal. Assistant to the President Science and Technology. "Testimony before the Subcommittee on Basic Research Committee on Science, United States House of Representatives." Jul. 14, 1999. Jun. 6, 2000. <http://www.whitehouse.gov/WH/EOP/OSTP/html/997_19_3.html>. 4.

[68] U.S. House of Representatives. H. R. 2086: Networking and Information Technology Research and Development Act. (Feb. 15, 2000) Jun. 8, 2000. < http://thomas.loc.gov/cgi-bin/bdquery/z?d106:HR02086:@@@D&summ2=m&>.

Another important bill that Congress is considering is the Federal Research Investment Act (S. 296). This act also addresses the problems of insufficient funding for long-term research. Over eleven years, federal funding of basic research, mostly through universities, will be doubled.[69] The bill also outlines a strategy for determining what projects should receive federal R&D funding. Presently the bill has passed the Senate and remains in House committee.

The Semiconductor Industry

The semiconductor industry perhaps has the greatest concern about the direction of computing hardware development. Solutions to the critical problems outlines earlier are vital if the industry is to survive well into the twenty first century. Consequently, the industry invests heavily in R&D. Thirteen percent of sales are invested in internal R&D each year.[70]
This is seven percent above the national average for R&D investment.[71] In 1998, the industry invested $9 billion on R&D, although most of this investment was for short-term applied development. Nevertheless, the industry has recently initiated a $60 million program for long-term university level research.[72] The new program directly addresses the fundamental problems that are impeding the development of more powerful microchips.

Much of the long-term research funded by the industry is accomplished through cooperative R&D ventures in a pre-competitive environment. These ventures include the Semiconductor

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[69] U. S. Senate. S. 296: Federal Research Investment Act. (Jul. 27, 1999) Aug. 1, 2000. < http://thomas.loc.gov/cgi-bin/query/D?c106:4:./temp/~c1068418gB::>.
[70] Bloch, Erich., Dr. Ralph Cavin and Kathleen Kingscott. "The Economy, Federal Research and the Semiconductor Industry." Semiconductor Industry Association. Mar. 8, 2000. 6.
[71] Bloch, Erich., Dr. Ralph Cavin and Kathleen Kingscott. "The Economy, Federal Research and the Semiconductor Industry." Semiconductor Industry Association. Mar. 8, 2000. 6.
[72] Semiconductor Industry Association. *R&D Funding*. Aug. 1, 2000. <http://www.semichips.org/rt/rdfund.htm>.

Research Corporation (SRC) and International SEMATECH. The SRC has invested $30 million per year into university research over the past fifteen years.[73] The semiconductor industry is very concerned about maintaining the rate of development predicted by Moore's Law. Its leading trade organization, the Semiconductor Industry Association (SIA), conducts a biannual report on the state of semiconductor technology. This report, called the International Technology Roadmap for Semiconductors (ITRS)[74], outlines critically needed research programs in fundamental technologies.

The results of the most recent report, released in 1999, raise serious concerns. SIA commissioned a special report, through the SRC, urging federal support for university research in fundamental physical sciences. The report stated the following conclusions:[75]

- "The physical limits to semiconductor performance are fast approaching and this will force a new technological revolution for which the science base is weak;
- In many of the critical physical sciences where physical understanding is important for the advancement of industrial technologies, there have been marked declines in federal research support;
- Foreign investment in semiconductor R&D is increasing;
- The decline of federal R&D as a percentage of U.S. R&D expenditures is threatening long term research, the historical province of the federal government;
- There is an inadequate supply of individuals with the advanced scientific and technological education to meet the needs of the semiconductor industry."

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[73] Semiconductor Industry Association. *R&D Funding*. Aug. 1, 2000. <http://www.semichips.org/rt/rdfund.htm>.
[74] International Technology Roadmap for Semiconductors: 1999 Edition." Semiconductor Industry Association. 1999. Jun. 8, 2000. <http://www.semichips.org/trade/techwhite.pdf>.
[75] Bloch, Erich., Dr. Ralph Cavin and Kathleen Kingscott. "The Economy, Federal Research and the Semiconductor Industry." Semiconductor Industry Association. Mar. 8, 2000. 1.

Based off of these conclusions, SIA proposed a "vigorous program of reinvestment by the federal government in basic university research in the physical sciences…"[76] through joint actions of the federal government and the industry. The following five actions are recommended:

1. **Strategy**

   A Federal R&D strategy needs to be developed for basic research in engineering and physical science to determine funding priorities. The semiconductor industry, through the SIA and SRC, has strategies that are annually reviewed. The industry spends a great deal of time thinking about its strategy.[77]

2. **Partnerships**

   SIA is committed to fostering, "cooperative industry efforts that leverage federal R&D efforts and through them enhance government, university and industry partnerships."[78]

3. **Education**

   SIA will continue to work with the government to,

   > "Develop programs that attract more U.S. students to the physical sciences and engineering in order to enhance the professional and technical workforce…"[79]

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[76] Bloch, Erich., Dr. Ralph Cavin and Kathleen Kingscott. "The Economy, Federal Research and the Semiconductor Industry." Semiconductor Industry Association. Mar. 8, 2000. 11.
[77] Cavin, Ralph. Semiconductor Research Corporation. Personal Interview. 17 Jul. 2000.
[78] Bloch, Erich., Dr. Ralph Cavin and Kathleen Kingscott. "The Economy, Federal Research and the Semiconductor Industry." Semiconductor Industry Association. Mar. 8, 2000. 11.
[79] Bloch, Erich., Dr. Ralph Cavin and Kathleen Kingscott. "The Economy, Federal Research and the Semiconductor Industry." Semiconductor Industry Association. Mar. 8, 2000. 11.

4. Research Infrastructure

> "SIA is committed to support federal government programs to assure that the infrastructure of government and university laboratories in equipment and capabilities to support forefront research in the physical sciences is maintained."[80]

5. Federal Programs

SIA supports the Federal Research Investment Act (S. 296) and the Networking and Information Technology Research and Development Act (H.R. 2086). SIA also supports full funding of the National Nanotechnology Initiative (NNI) and commits to working with the OSTP and participating agencies to develop specific aspects of NNI.[81]

Key Conflicts and Concerns

US concerns regarding IT R&D funding

- **Can industry afford to fund IT R&D on its own?**

A considerable philosophical debate exists about whether government should fund any R&D for information technologies (IT). Many researchers and scientists will argue that government support is absolutely critical. Others contend that government funding amounts to corporate welfare. However, many of the great advances in IT have some connection to government funding.

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[80] Bloch, Erich., Dr. Ralph Cavin and Kathleen Kingscott. "The Economy, Federal Research and the Semiconductor Industry." Semiconductor Industry Association. Mar. 8, 2000. 11-12.

[81] Bloch, Erich., Dr. Ralph Cavin and Kathleen Kingscott. "The Economy, Federal Research and the Semiconductor Industry." Semiconductor Industry Association. Mar. 8, 2000. 12.

Government supported high-risk R&D in basic sciences can potentially spawn new technology bases. Industry can then move in and capitalize on these new technologies. In 1969, the DOD's Advanced Projects Research Agency (ARPA) created an experimental nationwide computer network. In the late 1980's the National Science Foundation opened this network to universities and academic researchers. The network eventually led to the Internet. In the 1990's private companies were quick to move in on the Internet because many households owned computers. Additionally, there was an established knowledge base about computer networking. Industries did not need to worry about the reliability of network connections. Moving into online business was already considered risky. There was a time when investing in Amazon.com cost only $10 per share. Today shares go for several hundred dollars. In the early 1970's, very few individuals owned or had access to computers. There was no economic incentive for any private company to "invent" computer networking. The capital investment required for the necessary R&D would substantially outweigh the economic gains for almost 20 years. Yet, at the time there was a strongly recognized need to develop computer networking. Without government support, this technology would not have manifested.

The PITAC report strongly emphasizes the need for government to support long-term R&D because industries necessarily focus on shorter term and lower risk applied R&D.

> "The information technology industry expends the bulk of its resources, both financial and human, on rapidly bringing products to market. The U.S. information technology industry has created an awesome and continuous growth of capabilities based on the most intensely competitive marketplace the world has ever seen. Nearly every available person and dollar in this industry is focused on bringing the next version or the next product to market. Delivery product cycles are as short as every three to six months. The company that fails here misses the next short-term cycle and will not be successful."[82]

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[82] United States Office of Science and Technology Policy. President's Information Technology Advisory Committee. "Information Technology Research: Investing in Our Future." Feb. 1999. Jun. 8, 2000. <http://www.hpcc.gov/ac/report/pitac_report.pdf>. 8-9.

Another argument against government funded R&D is that it displaces private research money.[83] Foreign competitors can harm U.S. industry by exploiting the results of federally funded pre-competitive R&D. Thus, unless private industries can fund their own R&D, in house, and retain the services of the scientists, they will loose market share.

However, this argument fails when considering the need for federal funding of future computing hardware technologies. It assumes that the IT companies can afford to fully fund the necessary R&D in-house. The high cost and high risk of R&D in this area has already caused companies to band together and fund R&D at the pre-competitive level. SIA has stated, "It would be difficult for any single company to support the progressively increasing R&D investments necessary to evolve the technology…and finally to investigate and develop a set of new devices usable beyond the limits of [the present technology.]"[84] The problems the industry is facing are so significant that the application of R&D solutions may not be realized for ten or fifteen years. The risk and cost of developing and expanding a new technology base for computing are extraordinary. Even with the billions of dollars the industry has invested, there are still critical areas that need attention. If the government withdrew its support for this R&D, the semiconductor industry "could not fill the gap."[85]

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[83] Kealey, Terence. "End Government Science Funding." Cato Institute. Apr. 11, 1997. Jun. 8, 2000. <http://cato.org/dailys/4-11-97.html>. 1.
[84] International Technology Roadmap for Semiconductors: 1999 Edition." Semiconductor Industry Association. 1999. Jun. 8, 2000. <http://www.semichips.org/trade/techwhite.pdf>. Foreward.
[85] Bloch, Erich., Dr. Ralph Cavin and Kathleen Kingscott. "The Economy, Federal Research and the Semiconductor Industry." Semiconductor Industry Association. Mar. 8, 2000. 6.

- **Are we spending enough on long-term R&D?**

There is increasing concern about whether or not the federal IT R&D investment is inadequate. This is one of the PITAC committee's critical conclusions.[86] It is also the conclusion of the semiconductor industry's own analysis, "In many of the critical physical sciences where physical understanding is important for the advancement of industrial technologies, there have been marked declines in federal research support."[87] Although present funding levels for basic R&D are at higher levels than at any time in the past,[88] the present federal R&D investment is only 27 percent of the total. This represents a 20 percent decrease over the past 20 years.[89] According to the SRC, "The decline of federal R&D as a percentage of U.S. R&D expenditures is threatening long term research…"[90]

PITAC believes that federal R&D investment has, "not kept pace with IT's growing economic, strategic, and social importance to the Nation."[91] The committee claims three emerging trends are the result of insufficient federal support for IT R&D.

- "Research programs intended to maintain the flow of new ideas are turning away large numbers of excellent proposals.
- Current support is taking a short-term focus, looking for immediate returns, rather than investigating high-risk long-term technologies.

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86 United States Office of Science and Technology Policy. President's Information Technology Advisory Committee. "Information Technology Research: Investing in Our Future." Feb. 1999. Jun. 8, 2000. <http://www.hpcc.gov/ac/report/pitac_report.pdf>. 21-22.

87 Bloch, Erich., Dr. Ralph Cavin and Kathleen Kingscott. "The Economy, Federal Research and the Semiconductor Industry." Semiconductor Industry Association. Mar. 8, 2000. 1.

88 American Association for the Advancement of Science. *Table: Historical Data on Federal R&D, FY 1976-2000* Mar. 7, 2000. Jul. 26, 2000 <http://www.aaas.org/spp/dspp/rd/hist01p2.pdf>.

89 Bloch, Erich., Dr. Ralph Cavin and Kathleen Kingscott. "The Economy, Federal Research and the Semiconductor Industry." Semiconductor Industry Association. Mar. 8, 2000. 5.

90 Bloch, Erich., Dr. Ralph Cavin and Kathleen Kingscott. "The Economy, Federal Research and the Semiconductor Industry." Semiconductor Industry Association. Mar. 8, 2000. 1.

91 United States Office of Science and Technology Policy. "Interim Report on Information Technology: Questions and Answers." Aug. 10, 1998. Jun. 6, 2000. <http://www.whitehouse.gov/WH/EOP/OSTP/html/presstest/19980810_3.html>. 2.

- Computers and computing facilities on university campuses and other civilian research facilities are falling rapidly behind the state of the art."[92]

Opponents of increasing long-term federally funded IT R&D contend that private industry support for R&D is significantly higher than previous years. Although government is only funding 27 percent of the total U.S. R&D, this level of funding has increased since 1980. The decrease over the past 20 years from 50 percent to 27 percent has occurred from rising private sector R&D investments (see figure 4).[93]

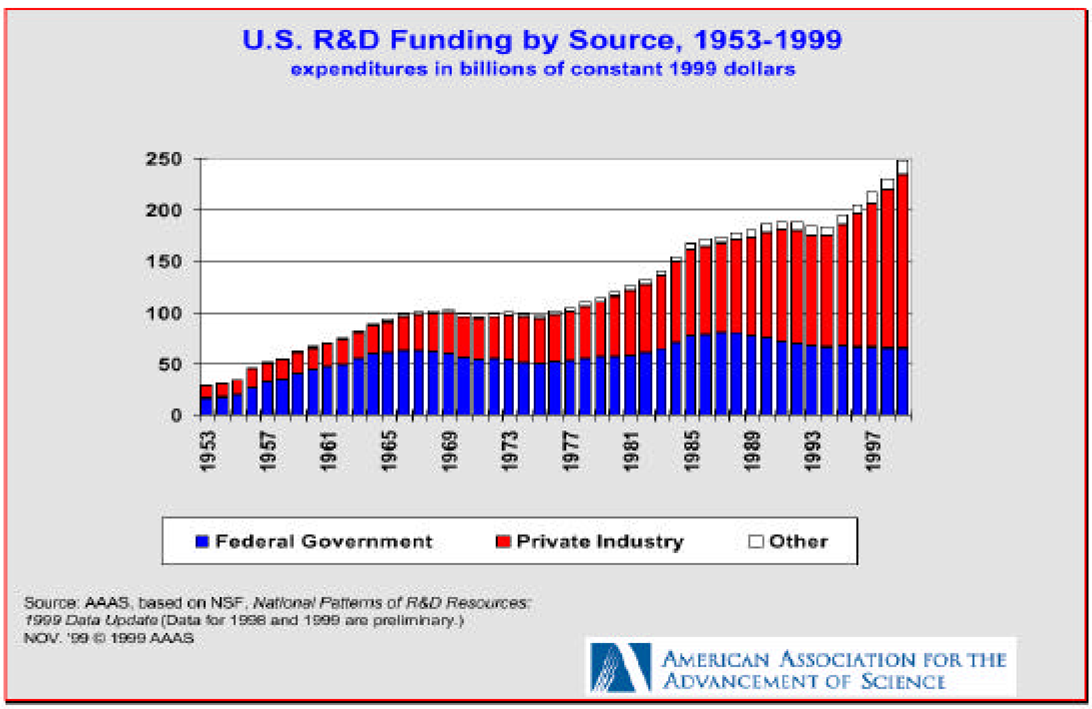

Figure 4. U.S. R&D Funding by Source, 1953-

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[92] United States Office of Science and Technology Policy. "Interim Report on Information Technology: Questions and Answers." Aug. 10, 1998. Jun. 6, 2000. <http://www.whitehouse.gov/WH/EOP/OSTP/html/presstest/19980810_3.html>. 2.

According to the Congressional Research Service (CRS), critics of the existing IT funding levels argue that, "the federal high-performance computing budget of over $1 billion is too large and represents an attempt by the federal government to influence commercial developments in high-performance computing."[94] Yet, the industry has outlined programs, through the ITRS, with areas of clear need of long-term support. In some instances, the type of federal funding necessary for realizing solutions, continues to decrease. SIA points out that "Federal investments in pre-competitive R&D, such as programs sponsored by the National Science Foundation, have declined over the past thirty years - from 5.7 percent of the Federal budget in 1965 to only 1.9 percent today."[95]

More money needs to be spent on long term IT R&D. The Industry calls for this, and has clearly outlined areas that need attention. Legislation such as HR 2086 and S. 296 both address this concern by providing increasing funding for basic IT R&D. S. 296, especially increases funding allocation to the areas that will most likely spawn the technology solutions the industry is craving; pre-competitive engineering and science research.

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[93] American Association for the Advancement of Science. *U.S. R&D Funding by Source, 1953-1999* Nov. 9, 1999. Jul. 26, 2000 <http://www.aaas.org/spp/dspp/rd/trendusr.pdf>.

[94] Congressional Research Service Report:
McLoughlin, Glenn J. "Computing, Information, and Communications R&D: Issues in High-Performance Computing." *Congressional Research Service Report for Congress* Congressional Research Service. Library of Congress. Mar. 25, 1997. CRS-7.

[95] Semiconductor Industry Association. *R&D Funding*. Aug. 1, 2000. <http://www.semichips.org/rt/rdfund.htm>.

- **Are H.R. 2086 and S. 296 the right solutions?**

H.R. 2086 and S. 296 attempt to address the concerns about present IT R&D policy. Both pieces of legislation increase funding for long-term basic research in IT, and support for both bills is widespread through out industry and academe. IEEE,[96] CRA,[97] and SIA have all endorsed the aims of the legislation. SIA has stated the following about S. 296,

> "With at least half of the total growth in the U.S. economy since the end of World War II attributable to scientific and technological innovation, the research done at universities and other publicly funded facilities provides a crucial base upon which private industry can build - further driving economic growth."[98]

However, there are some conflicting views about the nature of the R&D projects that are supported. Currently, there is a prevailing view by Congress that it is the proper role for government to invest in *long-term* basic R&D, so the debate is about whether several government funded project areas in H.R. 2086 are capable of being funded by private industry. One side believes there is not enough support for important programs critical to the future of IT, and that government funding should be increased. The other side believes many of these programs are short-term investments, and therefore not government's role to fund.

The Administration strongly supports the aims of H.R. 2086, but feels that important programs will be under supported. In testimony before the House Science Committee, Dr. Neal Lane, Assistant to the President Science and Technology, strongly praised the aims of H.R. 2086, but questioned the funding of several key programs.

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96 *Legislative Agenda for the 106th Congress (1999-2000)* Institute of Electrical and Electronics Engineers. Feb. 2, 1999.

97 Computing Research Association. "CRA Statement on the Networking and Information Technology Research and Development Act." *CRA Government Affairs* Jun. 29, 2000. Aug. 1, 2000. <http://cra.org/govaffairs/advocacy/nitrd_statement.html>.

98 Semiconductor Industry Association. *R&D Funding*. Aug. 1, 2000. <http://www.semichips.org/rt/rdfund.htm>.

> "H.R. 2086 provides insufficient levels of funding for DOE's support of new programs in terascale computing infrastructure and for other information technology research at DOE…The potential benefits [of this program] include developing exotic new materials essential for manufacturing, microelectronics, and many other areas;"[99]

Dr. Lane went on to criticize inadequate funding levels for other DOE programs, NIST, and NOAA.

Many in Congress consider these programs to shorter-term, and capable of being privately supported. Elizabeth Prostic, staff member of the Senate Committee on Commerce, Science, and Transportation specializing in IT, explained,

> "There is some concern about whether this research [addressed by H.R. 2086] is applied rather than basic research. Private industry can fund applied. High-tech companies spend very little on basic. Some [on the Committee] believe much of this research is applied, so there is some concern about whether this is needed."[100]

DOE's drastic budget cut was a reaction to this sentiment in Congress.

Whether or not these specific DOE projects are applied research, there clearly are other H.R. 2086 programs, and existing programs that raise questions. One NSF program, coordinated under the HECC Working Group, is *Automated Component Design*. This program supports, "basic research in Electronic Design Automation (EDA)," [101] and in applicable integrated circuit design technologies. The goals include, "covering all phases of the EDA design cycle for

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[99] Lane, Neal. Assistant to the President Science and Technology. "Testimony before the Subcommittee on Basic Research Committee on Science, United States House of Representatives." Jul. 14, 1999. Jun. 6, 2000. <http://www.whitehouse.gov/WH/EOP/OSTP/html/997_19_3.html>. 5.

[100] Prostic, Elizabeth. U.S. Senate Committee on Commerce, Science, and Transportation. Personal Interview. 18 Jul. 2000.

[101] United States Office of Science and Technology Policy. National Coordination Office for Computing, Information and Communications. "High Performance Computing and Communications: Information Technology Frontiers for a New Millennium" *FY 2000 Blue Book* Jun. 8, 2000. <http://www.hpcc.gov/pubs/blue00/hecc.html>.

integrated circuits and systems from conception through manufacturing and testing."[102] One of these research areas under this program is *System Design Methods*, which includes research for "systems-on-a-chip" technology. Presently semiconductor companies, like Intel[103] and Hewlett Packard[104], are actively working on this same technology. Critics believe this is a clear example of government support of applied research that is capable of being privately funded. Furthermore, this is being developed in a competitive environment, thus this government funding could potentially harm the industry, if these projects are funded at the pre-competitive arena.

Many of the H.R. 2086 programs in debate do not actively address the concerns about future computing hardware technologies. However, it is difficult to determine whether they may yield some benefit that helps expand the knowledge base. According to CRA, some of the programs may generate knowledge that is helpful for the design and implementation of future computing hardware technology.[105] Therefore, these projects should be maintained. Opponents argue that funding these questionably short-term projects siphons funding away from the critically needed long-term projects unable to be supported by industry.

Ultimately, there will likely be a compromise in funding levels. Both bills will probably be grouped together and pass in tandem.[106] Exactly what levels of funding the questionable projects

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[102] United States Office of Science and Technology Policy. National Coordination Office for Computing, Information and Communications. "High Performance Computing and Communications: Information Technology Frontiers for a New Millennium" *FY 2000 Blue Book* Jun. 8, 2000. <http://www.hpcc.gov/pubs/blue00/hecc.html>.
[103] Malik, Om. "Intel's Secret 'System on a Chip Plans.'" *Forbes.com* Aug. 9, 1999. Jul. 26, 2000. <http://www.forbes.com/tool/html/99/aug/0809/feat2b.htm>.
[104] Hewlett Packard. *HP Unveils New Production Testing Solution for LAN System-on-a-chip IC Devices* Mar. 4, 1999. Jul. 26, 2000. <http://www.europe.hp.com/pressrel/mar99/04mar99a.htm>.
[105] Thompson, Lisa. Computing Research Association. Personal Interview. 22 Jul. 2000.
[106] Prostic, Elizabeth. U.S. Senate Committee on Commerce, Science, and Transportation. Personal Interview. 18 Jul. 2000.

will receive is unknown. It is expected, however, that an effort will be made to ensure that long-term IT R&D projects receive priority.

Will semiconductor technology level out?

There is concern among industry officials that achieving the next generation of computing hardware technology may be so prohibitively expensive, that it will never be realized. The increasing costs of manufacturing microchips, has become known as *Moore's Second Law*, after Gordon Moore noted, "Capital costs are rising faster than revenue…the rate of technological progress is going to be controlled [by] financial realities."[107] In the May/June 2000 issue of *Technology Review*, Charles C. Mann describes Moore's Second Law as,

> "…painfully familiar to anyone associated with supersonic planes, mag-lev trains, high-speed mass transit, large-scale particle accelerators and the host of other technological marvels that were strangled by high costs… In the last 100 years, engineers and scientists have repeatedly shown how human ingenuity can make an end run around the difficulties posed by the laws of nature. But they have been much less successful in cheating the laws of economics."[108]

The semiconductor industry is beginning to show possible signs of maturing. G. Dan Hutchenson[109] and Jerry D. Hutchenson explain in the October 1999 issue of *Scientific American*.

> "The common theme in all these industries, from railroads to semiconductors, is that their initial phase was dominated by efforts to improve performance and to lower cost. In the [aerospace, railroad, and automobile] industries, which are considerably more mature, a second phase was characterized by product refinement and diversity."[110]

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[107] Mann, Charles C. "The End of Moore's Law?" Technology Review (May/June 2000) Jul. 26, 2000. <http://www.techreview.com/articles/may00/mann.htm>.
[108] Mann, Charles C. "The End of Moore's Law?" Technology Review (May/June 2000) Jul. 26, 2000. <http://www.techreview.com/articles/may00/mann.htm>.
[109] Founder of VLSI Research; a market-research firm specializing in semiconductor technology.
[110] Hutcheson G. Dan and Jerry D. Hutcheson. "Technology and Economics in the Semiconductor

Technology life cycles typically follow an S shaped pattern, marked by three sections (see figure

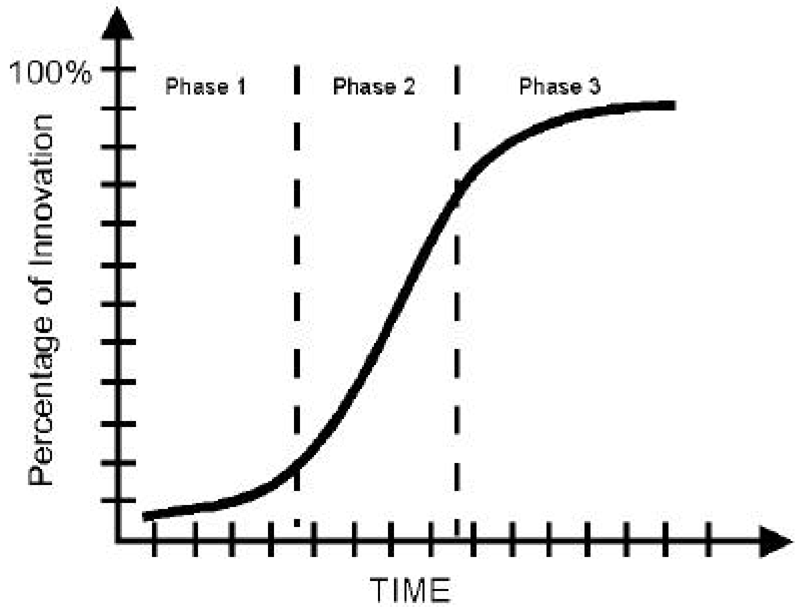

Figure 5. S-curve

5). In the beginning, progress is slow, as the new technology is adopted. The period in the middle is marked by rapid progress and innovation. Costs typically decrease to the consumer as the technology is further exploited. In the final section, most of the significant innovation has already occurred, and any improvements come from much slower refinement.

The Moore's Law rate of microprocessor progress can be considered to be the middle phase of the S-curve. The concern is that the industry may be nearing the final section, where the rapid pace that has fueled our economy will begin to plateau.

Companies like Intel are already branching out into more diverse areas, such as memory and communications. New processors are being designed to function in parallel architectures with other processors. Although this action results in increasing the level of processing power, unlike

Industry." *Scientific American* October 1999. pars. 36. Jun. 8, 2000.

the past, it does not come at a reduced cost. In this scenario, the cost increases linearly with the number of processors used.

This could be the fate of the industry, however, certain indicators suggest this may not have to occur. Early experiments in quantum and biological computing have already revealed surprising results. Some contend that analogies to the transportation industry may be incorrect because of the unique means by which the semiconductor industry has prospered. In *Crystal Fire, The Invention of the Transistor and the Birth of the Information Age*, Lillian Hoddeson and Michael Riordan point out, "The sustained explosion of microchip complexity—doubling year after year, decade after decade… has no convenient parallel or analogue in normal human experience."[111] The semiconductor industry could be approaching the top of the S-curve, or it could be approaching a point in the middle, similar to where the aerospace industry transitioned from propellers to jets.

Are we educating enough future engineers and scientists?

Overcoming the challenges faced by the semiconductor industry will require maintaining or increasing the size of the high-tech workforce. There is a great concern about the course of educating future technical professionals. According to the industry's research, "There is an inadequate supply of individuals with advanced scientific and technological education to meet

<http://www.sciam.com/specialissues/1097/solidstate/1097hutch.html>.

[111] Mann, Charles C. "The End of Moore's Law?" Technology Review (May/June 2000) Jul. 26, 2000. <http://www.techreview.com/articles/may00/mann.htm>.

the needs of the semiconductor industry."[112] To fill present IT workforce demands, industry must increasingly rely upon temporary workers such as H-1B visa holders.[113]

The results of the semiconductor industry's study show several unsettling trends.

- "Graduate electronic engineering degrees have been on the decline, in favor of [other technical degrees];
- The decrease in research funding by the federal government for semiconductor-related research in favor of biological science research attracts fewer students to this area;
- An SRC report predicts that the next cycle of growth in the semiconductor industry will bring hiring demand for engineers that could be significantly higher relative to the available supply of graduate engineers than what was experienced during the last peak (1995);
- Fewer foreign students remain in the U.S. after graduating and return to their home countries instead."[114]

Examining present spending levels on basic R&D for biological and life sciences verses support for physical science and engineering shows that there is increasingly greater support for the life sciences, (see figure 5)[115]. According to Elizabeth Prostic, Senate Committee on Commerce, Science, and Transportation staff member and IT specialist, it is important to have a uniform federal basic R&D portfolio. "Advances come form interplay between disciplines. [The United States] needs a balanced R&D investment."[116] This imbalance and the unsettling trends,

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[112] Bloch, Erich., Dr. Ralph Cavin and Kathleen Kingscott. "The Economy, Federal Research and the Semiconductor Industry." Semiconductor Industry Association. Mar. 8, 2000. 1.

[113] Institute of Electrical and Electronics Engineers. *Position: Ensuring a Strong High-Tech Workforce in the 21st Century*. Feb. 2000. Jul. 26, 2000. <http://www.ieeeusa.org/forum/POSITIONS/21cworkforce.html>

[114] Bloch, Erich., Dr. Ralph Cavin and Kathleen Kingscott. "The Economy, Federal Research and the Semiconductor Industry." Semiconductor Industry Association. Mar. 8, 2000. 9.

[115] American Association for the Advancement of Science. *Trends in Federal Research by Discipline, FY 1970-2000* Feb. 2000. Jul. 26, 2000 <http://www.aaas.org/spp/dspp/rd/discip00.pdf>.

[116] Prostic, Elizabeth. U.S. Senate Committee on Commerce, Science, and Transportation. Personal Interview. 18 Jul. 2000.

reported in the study, led the industry to call for, "[developing] programs that attract more U.S. students to physical sciences and engineering…"[117]

Government is aware of this shortage and the IT[2] initiative addresses these concerns. One of the three key areas that the initiative has highlighted for expanded research opportunity includes, "…the training of additional Information Technology workers at our universities."[118] H.R. 2086, in response to IT[2], directs NSF to provide grants for, "information technology education and training grants and internship grants."[119] There is other pending legislation, such

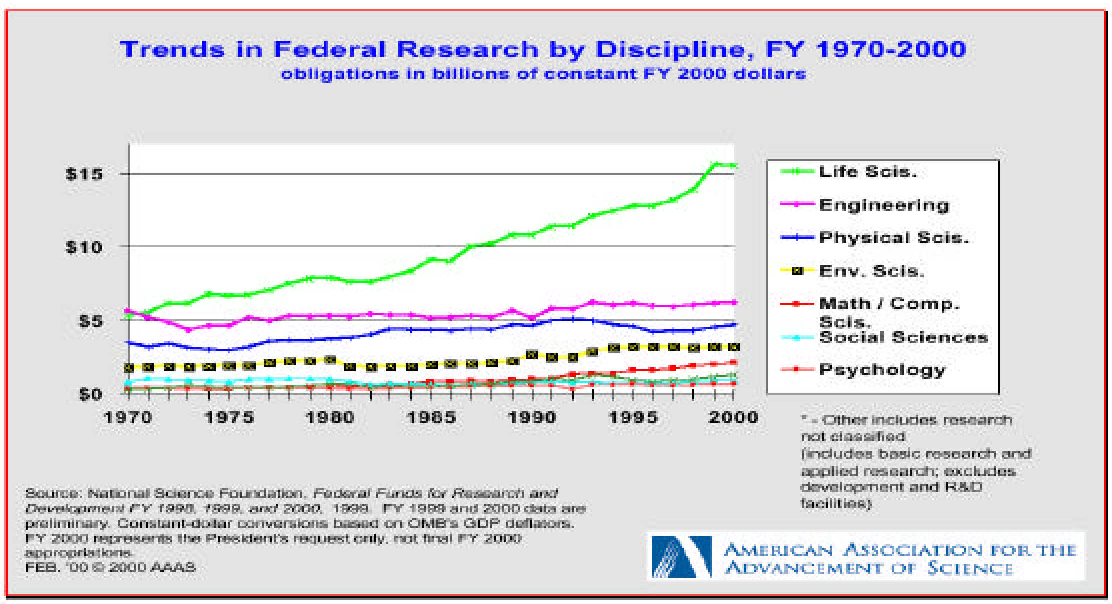

Figure 5. Trends in Federal R&D by Discipline

[117] Bloch, Erich., Dr. Ralph Cavin and Kathleen Kingscott. "The Economy, Federal Research and the Semiconductor Industry." Semiconductor Industry Association. Mar. 8, 2000. 11.

[118] United States Office of Science and Technology Policy. National Science and Technology Council. "Information Technology for the Twenty-First Century: A Bold Investment In America's Future." Jun. 1999. Jun. 8, 2000. < http://www.hpcc.gov/pubs/it2-ip/it2-ip.pdf>. 2.

[119] U.S. House of Representatives. H. R. 2086: Networking and Information Technology Research and Development Act (Referred in Senate). Sec. 4 c. (Feb. 15, 2000) Jun. 8, 2000. < http://thomas.loc.gov/cgi-bin/query/D?c106:4:./temp/~c106Mq9XJi:e669:>

as the *21st Century Technology Resources and Commercial Leadership Act*[120] that increases grants for advancing U.S. math, science, and engineering skills.

Recommended Policy Alternatives

- **Pass H.R. 2086 and S. 296**

Alternative: Pass with existing funding levels

If H.R. 2086 and S. 296 are passed with the present funding levels, then the increased long-term basic IT research, called for by the semiconductor industry, may occur for the time being. However, in an era with a critical eye toward government spending, efficient policy is crucial for the survival of the program. A large portion of IT R&D funding must compete against several other popular programs in Congress. For example, NSF information technology R&D programs must vie for funding against Veterans programs and Housing programs. These areas are very popular and represent large numbers of constituents. The number of constituents directly represented by long-term basic IT R&D programs is very small, and thus less likely to be a priority.

If H.R 2086 is funded at the present level, unnecessary short-term projects that weigh down costs may jeopardize the entire program. Greater spending on short-term R&D will result in lesser spending for long-term R&D. The desperately needed solutions, for the challenges faced by the

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[120] U. S. Senate. S. 1804: 21st Century Technology Resources and Commercial Leadership Act. (Oct. 27, 1999) Aug. 1, 2000. <http://thomas.loc.gov/cgi-bin/bdquery/z?d106:SN01804:@@@D&summ2=m&>.

industry, will come from long-term basic research. Industry only invests heavily in the short term, so government must fill this gap in long-term basic research.

Recommendation: Pass H.R. 2086 and S. 296 with modified spending levels

With a heavily scrutinized budget and programs tightly competing for support, priority must be given to long-term basic research unable to be sustained by private industry. Modify the spending levels in H.R. 2086 and S. 296 to encourage long-term R&D investment. Eliminate questionable short-term applied research that industry is capable of funding. Only short-term projects, that are vital for the development of new technology and unable to be supported by industry, should be supported.

• Create a focused long-term IT strategy

Alternative: No long term R&D strategy

Without any long-term R&D strategy, it will be difficult to ensure the needed areas of research are being supported. Solving the challenges that face the semiconductor industry will ultimately require developing and implementing a new technology base. The transition to that base, without a plan, will take much longer. Without a strategy, R&D spending is inefficient. Projects may overlap and duplicate. Unless important long-term basic research areas can be identified and given priority, the solutions the industry needs for tomorrow will never materialize.

Recommendation: Create a focused long-term IT R&D strategy

The present economic boom is largely due to advances in IT. It is vital that the U.S. take every measure possible to sustain the ongoing advance in IT since the state of tomorrow's economy may depend on it. Creating a formal focused strategy to ensure that R&D funding is efficient, necessary, and that the right areas are being addressed will result in a higher rate of return on U.S. investment.

S. 296 attempts to establish guidelines for federal R&D investment, and in so doing, outlines a sound investment strategy for IT R&D. The bill includes four "Guiding Principles"[121] for federal R&D programs: Good Science, Fiscal Accountability, Program Effectiveness, and Criteria for Government Funding. Under the fourth principle is a list of procedures for selecting which programs to fund.

> "Program selection for Federal funding should continue to reflect the nation's 2 traditional research and development priorities:
>
> (A) Basic, scientific, and technological research that represents investments in the nation's long-term future scientific and technological capacity, for which government has traditionally served as the principle resource; and
>
> (B) Mission research investments, that is, investments in research that derive from necessary public functions, such as defense, health, education, environmental protection, and raising the standard of living, which may include pre-commercial, pre-competitive engineering research and technology development.
>
> Additionally, government funding should not compete with or displace the short-term, market-driven, and typically more specific nature of private sector funding.
>
> Government funding should be restricted to pre-competitive activities, leaving competitive activities solely for the private sector.

[121] U. S. Senate. S. 296: Federal Research Investment Act (Referred in House). Sec. 5. (Jul. 27, 1999) Aug. 1, 2000. <http://thomas.loc.gov/cgi-bin/query/D?c106:4:./temp/~c106kh1Sfb:e173:>.

> As a rule, the government should not invest in commercial technology that is in the product development stage, very close to the broad commercial, except to meet a specific agency goal.
>
> When the government provides funding for any science, engineering, and technology investment program, it must take reasonable steps to that the potential benefits derived from the program will accrue broadly."[122]

These procedures fulfill a pivotal role in the establishing a long-term IT R&D strategy. However, although they will assure that selected projects meet our national objectives,

To make certain that U.S. IT R&D is moving in the right directions, there needs to be an annual or biannual review all IT R&D programs. Periodic reviews conducted by PITAC and the semiconductor industry will help to ensure that the right areas are being addressed.

Finally, the strategy must be mission oriented and include specific goals or milestones to work towards. This will aid in choosing which programs to support and recognizing new program areas that need to be developed. Additionally, attaching deadlines with these goals allows the projects to be prioritized.

• Fund the National Nanotechnology Initiative

Alternative: Do not fund the National Nanotechnology Initiative

Nanotechnology has the potential to solve many of the problems society is presently faced with. Cures for disease, the end of famine, and solutions for future computing hardware technologies

[122] U. S. Senate. S. 296: Federal Research Investment Act (Referred in House). Sec. 5 b. (Jul. 27, 1999) Aug. 1, 2000. <http://thomas.loc.gov/cgi-bin/query/D?c106:4:./temp/~c106kh1Sfb:e173:>.

are possible from nanotechnology. However, presently very little is known about nanotechnology. The field exists only at the level of basic R&D and its practical application may be over 15 years away. Because the industry avoids investing in long-term high-risk R&D, such as nanotechnology, with out government support, the benefits of nanotechnology may never be realized, or may take much longer to appear.

Recommendation: Fund the National Nanotechnology Initiative

Nanotechnology R&D truly is a very long-term and high-risk area with extremely promising returns. Therefore it is an ideal candidate for government support. The long-term solutions for the problems confronting the semiconductor industry will probably be reached through nanoelectronics. Another very promising future computing hardware technology, molecular computing or biochemical computing, is under the realm of nanotechnology. Additionally, the bottom up approach (Foot note), permitted through nanotechnology, could eliminate many of the manufacturing difficulties presently existing with semiconductor fabrication.

- ## Develop programs that attract more students to Engineering and Physical Sciences

Alternative: Do nothing

Presently IT education is caught in a downward spiral. A federal trend of decreasing R&D funding[123] has resulted in fewer research opportunities at the university level. With fewer opportunities for education, such as reduced faculty and research grants, fewer students have

[123] U. S. Senate. S. 296: Federal Research Investment Act (Referred in House). Sec. 2 b. Part 3. (Jul. 27, 1999) Aug. 1, 2000. <http://thomas.loc.gov/cgi-bin/query/D?c106:4:./temp/~c106kh1Sfb:e173:>.

moved into certain technical fields. The high-tech workforce has diminished because there are fewer students graduating with degrees of those same fields. The smaller workforce is less productive, and less capable of solving problems of the industry. Consequently, the growth of the industry is limited resulting in fewer opportunities for R&D in critical areas.

The SRC has identified three following alarming trends that, if left to continue, could seriously erode the high-tech workforce.

- "The inadequate K-12 education, which does not prepare students for the rigor and prerequisites of a science and engineering education;
- The under representation of large portions of our society, e.g., women and minorities, in the science and engineering fields;
- Reduction in faculty because of reduction in research funding exacerbates the reduction in students in these fields;"[124]

Unless adequate programs, to increase the number of engineering and physical science students, are created, the IT field will continue to suffer and the critical problems facing the semiconductor industry may go unsolved.

Recommendation: Develop programs that attract more students to Engineering and Physical Sciences

Government and industry must work to increase the number of high-tech graduates or the industry will suffer. SRC has called for, " [the] Coupling of university research grants, by government and the SRC, with undergraduate research opportunity - even at the high school

[124] Bloch, Erich., Dr. Ralph Cavin and Kathleen Kingscott. "The Economy, Federal Research and the Semiconductor Industry." Semiconductor Industry Association. Mar. 8, 2000. 10.

level…."[125] The semiconductor industry has recently initiated a $60 million university level research program, and has funneled over $30 million into universities, each year, over the past fifteen years. Passing H.R. 2086 and S. 296 will also increase university level R&D funding, thereby expanding undergraduate research opportunities. S. 296 notes the importance of partnering education with research opportunity.

> "Federal investment in science, engineering, and technology programs must foster a close relationship between research and education. Investment in research at the university level creates more than simply world-class research. It creates world-class researchers as well."[126]

According to a Congressional Research Service report many in academia consider federal efforts to support research and education vital for creating a competent high-tech workforce.[127] H.R. 2086 proposes "Information Technology Education and Training Grants."[128] These include *information technology grants* for universities, *internship grants* to higher education institutions for establishing partnership internship programs with private sector companies, and *matching funds* for private sector companies to create and support internship positions.

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[125] Bloch, Erich., Dr. Ralph Cavin and Kathleen Kingscott. "The Economy, Federal Research and the Semiconductor Industry." Semiconductor Industry Association. Mar. 8, 2000. 11.

[126] U. S. Senate. S. 296: Federal Research Investment Act (Referred in House). Sec. 4. Part 4. (Jul. 27, 1999) Aug. 1, 2000. <http://thomas.loc.gov/cgi-bin/query/D?c106:4:./temp/~c106kh1Sfb:e173:>.

[127] Congressional Research Service Report:
McLoughlin, Glenn J. "Computing, Information, and Communications R&D: Issues in High-Performance Computing." *Congressional Research Service Report for Congress* Congressional Research Service. Library of Congress. Mar. 25, 1997. CRS-7.

[128] U.S. House of Representatives. H. R. 2086: Networking and Information Technology Research and Development Act (Referred in Senate). Sec. 4. (Feb. 15, 2000) Jun. 8, 2000. < http://thomas.loc.gov/cgi-bin/query/D?c106:4:./temp/~c106Mq9XJi:e669:>

Conclusion

The U.S. is at a critical juncture. The economic boom we are experiencing exists from the success of the IT industries and the ongoing advances in technology. The semiconductor industries ability to deliver more computer processing power for less cost has driven the IT revolution, but the future of this ability is now in question. Certain actions must be taken if the industry is to continue following Moore's Law. Certain policies must be adopted if the nation is to sustain the prosperity introduced through Moore's Law.

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