Woodrow Wilson International Center for Scholars

Science, Technology, America, and the Global Economy

Funding the Foundation:

BASIC SCIENCE AT THE CROSSROADS

Edited by Kent Hughes and Lynn Sha with Caroline Vazquez

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Introduction

KENT. H. HUGHES, Director, Program on Science, Technology, America, and the Global Economy, Woodrow Wilson International Center for Scholars

SCIENCE AND TECHNOLOGY POLICY IN THE 21ST CENTURY

New technologies and the scientific developments that often stand behind them are transforming America, the world economy, and the entire planet. The Internet and the deciphering of the human genome are the latest in two centuries of innovation that brought enormous prosperity, lengthened lives and shrunk distances around the world. In the 21st century, new discoveries and technologies will continue to create opportunities and pose significant policy and ethical challenges.

In an effort to help clarify the debate surrounding science and technology policy, the Woodrow Wilson International Center of Scholars has expanded and renamed an existing project as the Program on Science, Technology, America, and the Global Economy (STAGE). Part of STAGE's agenda will be to explore the impact of technological developments on the politics and economics of key regions of the world. The technological prowess of Europe and Japan are now familiar to American political and business leaders. But the impact of technology is now much broader. In our view, you cannot talk about the Indian economy without thinking of Bangalore and the provision of on-line business services; or discuss China without recognizing its growing capacity for sophisticated manufacturing; or ignore Brazil as it becomes a leading competitor in the field of regional jet aircraft.

New technologies with roots in the physical and life sciences raise ethical questions and pose new challenges for policymakers. STAGE, along with other Center programs, will explore the ethical and policy dimensions that have emerged along with new technologies.

Many countries are now seeking to adopt and adapt the successful American model of innovation that has combined enduring support for basic science, world class research universities, and an entrepreneurial tradition that has helped translate new ideas into life enhancing products and processes. The race for new innovations has created a growing demand for highly educated scientists and engineers. For much of the 20th century, the United States benefited from a steady flow of scientific talent from around the world. Now, Europe, Asia, and other parts of the world are competing to attract that talent or keep more of it at home.

The spread of a culture of innovation promises enormous benefits for the world. But, it also poses a challenge to the standing of the United States both as a leading innovator and an economic power. As part of the Wilson Center's increased focus on science and technology, the Center will explore the policies needed to maintain and enhance America's capacity to pioneer new scientific and technological discoveries, develop new processes and products, and capitalize on new technologies where ever they are invented.

As part of the Center's expanded focus on science and technology policy, STAGE is launching a new, occasional series of essays, conference reports, and analyses on different aspects of science and technology policy. Our first conference report, *Funding the Foundation: Basic Science at the Crossroads,* features a talk by Dr. Shirley Ann Jackson, president of Renssalaer Polytechnic Institute and a panel discussion with Robert Helms, Dean of the Erik Jonsson School of Engineering and Computer Science at the University of Texas at Dallas, Robert Doering of Texas Instruments, and John Stratton of Lockheed Martin. Together they emphasize the critical importance of adequate government support and funding of physical science for its contribution to university-based discovery and education, industrial innovation, and national security.

In her talk, Dr. Jackson points to the failure of funding for the physical sciences to keep pace with the growth of the U.S. economy. While the life sciences have been more amply funded, Dr. Jackson notes that new medical discoveries often depend on advances in a number of disciplines in the physical sciences.

Dr. Jackson saw the development of a culture of innovation in other parts of the world as holding out enormous promise for us all. But she also stressed the need for the United States to take added steps to build its own capacity to generate new ideas and new technologies. She called for increased funding for the physical sciences, a welcoming posture to overseas scientists and students, and a greater emphasis on math and science in the nation's K-12 education system.

The panel amplified many of Dr. Jackson's themes. Dean Helms pointed to Sputnik and the U.S. space program as the magnet that drew many young people into careers in science and engineering. We need, he stressed, a similarly compelling mission today. Robert Doering pointed to the complementary role played by government and business in the world of semiconductors with the government providing critical support as a first customer and as a funder of needed research. John Stratton of Lockheed Martin made similar points about the defense industry by noting how the defense industrial base drew on federally funded basic research.

In the months ahead, the Program on Science, Technology, America and the Global Economy will explore other facets of science and technology policy and their role in defining the 21st century.

Chapter 1

Opening Remarks

FREDERICK M. BUSH, **Associate Director, Woodrow Wilson International Center for Scholars**
KENT. H. HUGHES, Director, Program on Science, Technology, America, and the Global Economy, Woodrow Wilson International Center for Scholars

On behalf of the Woodrow Wilson Center and our president, Lee Hamilton, I want to thank you for coming to this interesting forum today. We look forward to exploring one of the challenges facing the scientific, engineering, and technological communities—the critical need for increased federal support for university research and development programs. We are honored today to have Shirley Ann Jackson, one of the country's foremost experts in that field, with us.

I especially want to give a word of thanks to our partners who helped put on today's forum, Gray Mayes of Texas Instruments, Sharon Venable of the Greater Dallas Chamber, Claire Emerson of the AeA Texas Council, and Julie Paul of TechNet: Texas.

A little bit about the Woodrow Wilson Center: Founded in 1968 as part of the Smithsonian Institution and headquartered in Washington, we are the living memorial to President Wilson. To describe us best would be to say we are a nonpartisan government center for research and dialogue in public policy. Some people say we are a university without professors or classrooms. We are not an advocacy group but instead a platform for thoughtful discussion, and we are often referred to as the only truly nonpartisan platform in the nation's capital.

Our mission is to help bridge the worlds of academia, policy, and business by promoting research and dialogue. Through conferences and meetings such as this one, through broadcasts and publications, the Center provides a vital link between the world of ideas and the world of public policy. We hold over 700 meetings and seminars a year, mostly in our center in Washington. We bring together scholars, public policymakers, and business leaders believing, as Woodrow Wilson did, that free and open discussion will lead to better understanding and better policy. He was a scholar, the only president to have earned a Ph.D., and he wrote often about the need to bring policymakers, many of whom live in the nation's capital area, together with academicians, with the goal of achieving better scholarship; that was important to him. But even more important to him as a politician was that the country would have better-informed public policymakers.

It is my pleasure today to introduce my most esteemed colleague, Kent Hughes. I want to thank Kent and my colleague, Susan Metts, for contributing the Woodrow Wilson Center's side of today's forum. Kent is the director of the Center's Program on Science, Technology, America, and the Global Economy, one of the Center's newest programs, that identifies and targets the policies, practices, ideas, and institutions that foster sustainable growth in domestic and international economies.

KENT HUGHES

The focus of today's session builds on some of the work that we have been doing at the Wilson Center and highlights a greater emphasis at the Center on science, technology, and public policy. In part, we are responding to the new challenge the United States faces from an ever more competitive global economy. We have always been leaders in innovation; certainly for all of our lives the United States has been the world innovation leader. It has given us an edge in the economy and a very critical edge in terms of military strength. Now we are being challenged by efforts in Europe, in East and South Asia, and other rising economies around the world. There is no question that the world is looking at a model for innovation that has been so successful for us. Attempting to emulate it, they are creating a new set of opportunities and challenges for us.

We are extremely fortunate to have with us a leading authority in the field, Dr. Shirley Ann Jackson, the 18th president of Rensselaer Polytechnic Institute (RPI), located in Troy, New York near Albany. I have had the pleasure of visiting RPI myself. If any of you chance to be in that area, do not miss the opportunity to visit the campus. They have a range of imaginative programs, a terrific manufacturing curriculum, and an incubator to help commercialize new ideas. They really are a cutting edge engineering school.

I am just going to give you a few highlights of Dr. Jackson's career. If I gave even the short version of her bio we could be here all morning. She is the president of the American Association for the Advancement of Science, a member of the National Academy of Engineering, and a member of the Federal Academy of the Arts and Sciences. She sits on the boards of a range of other important public institutions as well as a number of leading private institutions, including the New York Stock Exchange. She has, in addition to her academic background and private sector exposure, a very distinguished record of public service. She served from 1995 to 1999 as the chairman of the U.S. Nuclear Regulatory Commission; not surprisingly, she also has an extremely distinguished academic background.

Chapter 2

Insuring Security by Assuring National Capacity: A Two-Fold Mission

PRESENTED BY

Shirley Ann Jackson, Ph.D.

President, Rensselaer Polytechnic Institute

Good morning. I begin with the following premise: the United States, in conjunction with the multi-national community as a whole, can better maintain its own security and a global security by exploiting scientific discovery and invention for two vital purposes: to develop thriving markets within and among nations, and to utilize innovation to resolve problems and to address the rising expectations of the world's people.

I offer this premise even while, as a nation, we are in the midst of two struggles. One is an international struggle against terrorism, which most see as an acute threat. The other is a struggle for sustaining our national scientific and technological capacity. And, while we are fully engaged in the one, we have been ignoring the other, which is directly related to the former, and, ultimately, may prove to be of greater import.

This is not a new issue. In February of 2001, the U.S. Commission on National Security/21st Century (the Hart-Rudman Commission) released its "Road Map for National Security" making five recommendations. Two are important here. The first was ensuring the security of the American homeland. The second was "recapitalizing America's strengths in science and education." The commission said although we have enjoyed the economic and security benefits of previous investments in science and education, we now have crossed a line and are "consuming capital." This poses:

> *"a greater threat to U.S. national security over the next quarter century than any potential conventional war that we might imagine."*

The Hart-Rudman Commission focused, by design, on the security of our national borders and our national interests. But, the benefits of scientific discovery and technological innovation unfold beyond national borders with collateral benefit. Discoveries and innovations extend to peoples and governments in both developed and developing nations, enabling them to address embedded problems and to participate in a technology-driven global economy.

Some embedded problems are cultural, religious, political, social, and must be addressed in that way. Others, if not completely solvable, are, at least, addressed through exploitation of scientific discovery and technological innovation, and through education.

I will make two key points: one is the criticality of investment in basic research, and the second is the urgent need to invest in human capital development to assure that we have the scientists and engineers to make the scientific discoveries and technological innovations of tomorrow.

For decades, the investment in scientific research by the United States has produced innovations, developments, products, and processes which have improved our national security, health, and prosperity, and have raised the quality of life. These same investments, in scientific research and discovery, and in the development of human intellectual capacity, are rising, now, in other nations, as well. The sum will be of global benefit.

These investments, while welcome overall, raise the question of whether the United States will continue to make sufficient investment—and, a sufficiently balanced investment—to maintain its own capacity for scientific discovery and technological innovation, and to remain a leading player in an increasingly competitive global marketplace.

Therefore, I will focus, here, on innovation and what it can achieve, and on education.

I will make two key points: one is the criticality of investment in basic research, and the second is the urgent need to invest in human capital development to assure that we have the scientists and engineers to make the scientific discoveries and technological innovations of tomorrow.

The idea of innovation has been around a long time. Fifty years ago innovation was closer to invention—i.e. discovery and creation in and of themselves. Today, more value is given to the exploitation of what comes from discovery and creation—commercially, socially, and militarily. In a sense, this reflects the success of the early Vannevar Bush model of innovation based on the investment—through a partnership of government and academia—in basic research and the development of scientific talent. Embedded in the original investment in basic research and human resource development was a promissory note—that such investment would redound to the benefit of society. Initially, "society" was nationally focused, and "benefit" related primarily to national security. But, as new discoveries were made and technologies evolved, the long-term benefits were far broader—and, included huge commercial and economic payoffs—extending to global commerce and advances in energy, health, transportation, and many other sectors. The present affluence of the U.S. owes much to this investment and to the ease of global 'migration' (both literal, with modern transportation, and virtual, with the Internet and global communications networks).

Economists estimate that as much as half of U.S. economic growth over the past five decades has been due to the advances made in technology.[1] Consider air transportation, atomic energy, jet and rocket propulsion, other space technologies, communications, television, computers, semiconductors, microchips, laser optics, fiber optics—developments which revolutionized life and spawned new industries.

History demonstrates that we do not typically know the significance of scientific breakthroughs. When the transistor was invented in 1947, *The New York Times* reported only that the device might lead to better hearing-aids. Instead, transistors are essential to almost every system or device manufactured today—computers, cameras, cars, spacecraft, missiles, and more.

These achievements, themselves, evolved even further with the rise of computer science and greater computational capability brought about by the marriage of quantum science and micro-fabrication techniques to develop microprocessors, nanoscale devices, integrated circuits, among others. These advances resulted from the nation's investment in basic research.

Consider, today, the rise of nanotechnology. Nanotechnology is a quintessentially multi-disciplinary field, with a wide variety of promising applications resulting from the fundamental research.

If someone asked you to design more effective armor for soldiers, would you begin by studying the manipulation of matter at the molecular level? Probably not. And yet, researchers in nanotechnology—the practice of manipulating matter at the atomic or molecular level—have made great strides toward developing strong protective clothing for soldiers, in the form of "dynamic armor" which can be activated quickly on the battlefield.

In another example, scientists at Johns Hopkins University have developed a self-assembling protein gel which stimulates biological signals to quicken the growth of cells. Using a combination of cells, engineered materials, and biochemical factors, the gel can replace, repair, or regenerate damaged tissues.[2]

Pharmaceutical research has given us the "animal-on-a-chip." Combining nanotechnology, microfluidics, and biological materials, the "animal-on-a-chip" can reproduce the effects of chemical compounds in the human body. The application of information technology for mathematical modeling and simulation of chemical reactions in the body, combinatorial chemistry for potential drug identification, coupled with accelerated and efficient screening by high throughput processes will allow faster analysis, shortened time to market, and substantially lower development costs for new pharmaceuticals.

Contemporary research leaps traditional boundaries, as once distinct disciplines necessarily inform each other, achieving new breakthroughs. What

History demonstrates that we do not typically know the significance of scientific breakthroughs. When the transistor was invented in 1947, *The New York Times* reported only that the device might lead to better hearing-aids. Instead, transistors are essential to almost every system or device manufactured today—computers, cameras, cars, spacecraft, missiles, and more.

The scientific breakthroughs of today become the transformative technologies of tomorrow, and because we do not know where the next discovery may be, where innovations will come from, or where they, ultimately, may lead, investment in basic research is critical.

today are being attributed as life science breakthroughs are just as much physical, information, and computational science breakthroughs. The very idea of nanotechnology and its promise rest on the physical, information, and computational sciences. The ability to image at the molecular level and to manipulate at the molecular level, in physical and living systems, is a breakthrough of physics, chemistry, and engineering. The ability to design new targeted drugs and other disease treatment modalities, based on genomic achievements, depends upon computational and nano-science capabilities.

The interdependency of one field upon another requires support across a broad front which includes the traditional life sciences, and the physical and engineering sciences.

But, we are at a critical juncture. The war on terror, the uneven economic expansion of the last three years, and the federal budget deficit have weakened government resolve to invest in basic research. This is happening just when we should be investing more—not less. As the lesson of the transistor shows, the scientific breakthroughs of today become the transformative technologies of tomorrow, and because we do not know where the next discovery may be, where innovations will come from, or where they, ultimately, may lead, investment in basic research is critical.

It is incumbent upon the United States to continue investment in basic research—not only for the benefits it may reap for our country, but also to help in eliminating the growing disparities among and between peoples of the world. These disparities, coupled with the concomitant hope to share in the benefits and prosperities they observe, speak to the rising expectations of peoples around the globe. One might view this as a matter of enlightened self-interest—or, the generous responsibility of a preeminent global leader.

The primary challenge of the developed world is to deal with terrorism by dealing with the causes of terrorism—primarily in the Third World. Fundamental research and the innovations which derive from it give us a way to do this directly, with benefits accruing to all, particularly as they relate to food, health, infrastructure, and environment.

Food, where genetically engineered, insect-resistant crops may come into play. Health, where new medicines and new disease treatment modalities come into play. Infrastructure and environment, where new engineering solutions for clean water and sustainability are important. No nation can grow and prosper economically without these needs addressed.

Continued, balanced investment in basic research is one critical factor. But, who will do the science in the 21st century?

World War II was won on the talents of scientists and engineers whose work gave the nation weapons systems, radar, infrared detection, bombers, long range rockets, and torpedoes.

As a cold-war continuation of the national defense effort, the Rand Corporation engaged in basic, super-secret research. During summers of the early 1950s, a young, and somewhat peculiar, mathematician from Princeton joined their ranks. The work of John Forbes Nash on "game theory" would become the most influential theory of rational human behavior, ultimately revolutionizing the field of economics. The work won Dr. Nash a Nobel Prize in Economics in 1994.[3]

Game theory opened new ways of thinking and analysis. It gave the government a new way to sell access to public resources through auctions—oil leases, T-bills, timber, pollution rights—to corporations and conglomerates in order to develop them.

Early in his career, Dr. Nash succumbed to schizophrenia—recovering, miraculously, three decades later. His story is told in the book, *A Beautiful Mind*, by Sylvia Nasar, later made into a movie. His story is filled with individuals and institutions which accepted his unique diversity, and made every effort to enable him to continue to work.

Princeton University also presents another interesting lesson. In the 1930s and 1940s, when other universities [e.g. Harvard] declined to offer positions to Jewish refugee scientists and mathematicians fleeing Nazi Germany, Princeton opened its doors. The result was a constellation of brilliance at Princeton anchored by Albert Einstein.

The lesson of Princeton in this period is that talent resides in many places—sometimes unappreciated or under-appreciated. The very group (or individual) a society may ignore or neglect may be the very group (or individual) which makes the greatest discoveries or achieves the greatest innovations.

The lesson of Princeton in this period is that talent resides in many places—sometimes unappreciated or under-appreciated. The very group (or individual) a society may ignore or neglect may be the very group (or individual) which makes the greatest discoveries or achieves the greatest innovations. We have made such mistakes in the past.

If we make such mistakes today, in the face of several converging factors, a worst-case scenario could arrest our national scientific and technological progress and global leadership. The forces at work are demographic, political, economic, cultural, even social.

I liken the situation to "The Perfect Storm."

The phrase is associated with meteorological events of October 1991, when a powerful weather system gathered force, ravaging the Atlantic Coast. The event became a book, and, later, a movie.

Meteorologists, observing the event, emphasized the unlikely confluence of conditions where multiple factors converged with devastating magnitude.

The forces at work today, which could have a similar devastating effect on our future scientific and engineering workforce, are four-fold.

Science and engineering degrees now represent 60 percent of all bachelor's degrees earned in China, 33 percent in South Korea, and 41 percent in Taiwan. By contrast, the percentage of those taking a bachelor's degree in science and engineering in the U.S. remains at roughly 31 percent.

- **First,** our scientific and engineering workforce is aging. Half of our scientists and engineers are at least 40 years old, and the average age is rising. As a recent National Science Foundation survey states, "the total number of retirements among science and engineering-degreed workers will dramatically increase over the next 20 years.

- **Second,** world events, including the terrorist attacks of September 11, 2001, and resulting adjustments in federal immigration policy, have made the United States less attractive to international students and scientists, long a source of talent which has augmented our own. Since 2001, visa applications from international students and scientists have dropped. Faced with new hurdles, students from other nations are choosing to study elsewhere.

- **Third,** the countries which have been primary sources of science and engineering talent for the United States—China, India, Taiwan, South Korea—are making a concerted effort to educate more of their own at home, and to fund more research within their borders. Between 1986 and 1999, the number of science and engineering doctorates granted increased 400 percent in South Korea, 500 percent in Taiwan, and 5,400 percent (that is correct—5,400 percent) in China. Not surprisingly, the number of South Korean, Taiwanese, and Chinese students receiving doctorates in the United States declined in the late 1990s. During the decade from 1991 to 2001, while U.S. spending on research and development was rising about 60 percent, spending rose more than 300 percent in South Korea and about 500 percent in China,[4] albeit from an initially much smaller base. In addition, improving global economies are offering young scientists from these and other countries more job options at home, or in other nations.

- **Fourth,** fewer young Americans are studying science and engineering. Moreover, the proportional emphasis on science and engineering is greater in other nations. Science and engineering degrees now represent 60 percent of all bachelor's degrees earned in China, 33 percent in South Korea, and 41 percent in Taiwan.[5] By contrast, the percentage of those taking a bachelor's degree in science and engineering in the U.S. remains at roughly 31 percent. Graduate enrollment in science and engineering reached a peak in 1993, and, despite some recent progress, remains below the level of a decade ago.

Individually, each of these four factors would be problematic. In combination, they could be devastating. For the first time in more than a century, the United States could well find itself losing ground to other nations. Indeed, recent measures of relative scientific productivity and achievement suggest that the U.S. may be losing its dominance in the sciences: Nobel Prizes, scientific publications, patents issued.

The "Perfect Storm" need not unfold, however, if we draw on the talent extant in youth who, traditionally, have been underrepresented in science, engineering, mathematics, and technology. This means reaching out to minority youth and young women, who now comprise but a small portion of our scientists and engineers, yet in sheer numbers together constitute "the new majority"—the "under-represented" majority.

In the last decade, the population of the United States grew from 248.7 million to just over 281.4 million. The non-Hispanic white population grew by roughly 3 percent, while the Hispanic population expanded by 57.9 percent, the Asian-American population by 52 percent, and the African-American population by 15.6 percent. The total minority population of the United States is now more than 30 percent.[6] When women are added to the mix, "the new majority" emerges.

By contrast, the traditional science, mathematics, engineering, and technology workforce is still nearly 82 percent white and 75 percent male.[7] Clearly, there is a large demographic disparity between the scientific and technological workforce of the present, and the general college-educated population of the future.

It is no accident that for, perhaps, 150 to 200 years the United States has been a global leader, or that this nation has been the source of so much that is visionary, transformative, new. This is because our inherent diversity has been a strength, and a key component of our sustained global leadership.

Immigrants—new Americans—coming for decades to our shores, from all parts of the globe, brought with them (and, still bring) a unique determination to improve their lives, and an eagerness to participate in U.S. society, and to contribute to it. Here, they have pooled their vastly differing talents, wide experiences, unique ideas, perspectives, and cultures. This diverse mix, this great "smelting pot," has been the crucible from which has poured a great array of world-changing discoveries, innovative technologies, life-sustaining initiatives, and transformative ideas.

There is a lesson here for us.

To arrest the "Perfect Storm," we need a full-fledged national commitment to invest in research in science and engineering, to re-ignite the interest in science and mathematics of all of our young people, and to

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identify, nurture, mentor, and support the talent which resides in our "new majority" population. But, how do we encourage talented students to commit themselves to the sciences as early as middle school? To stay the often difficult course through high school? To find the means to attend the university, and continue through post-graduate work? To transition into the workplace, the laboratory, the design studio?

We need a full-fledged national commitment to invest in research in science and engineering, to re-ignite the interest in science and mathematics of all of our young people, and to identify, nurture, mentor, and support the talent which resides in our "new majority" population.

Some incentives necessarily must be financial. President Bush recently has voiced his approval for Pell Grants that especially aid low-income students entering the sciences. I would welcome an even more complete extension of this approach. This would require more economic support for such students, but also support for a broader socioeconomic range of students (of all ethnic backgrounds), and at all educational levels, through graduate school. An example could be patterned on portable fellowships like those once offered as a result of the National Defense Education Act (NDEA) for graduate study in science and engineering.[8]

The U.S. government, trade associations, and a variety of other organizations are funding many public-private partnerships to address the issues. Two years ago, the National Science Foundation (NSF) and the U.S. Department of Education (DOE) launched the Mathematics and Science Partnership Program,[9] which helps to support needy school districts implementing cutting-edge programs—to improve teaching and learning. Each is a collaborative effort involving institutions of higher education, school districts and, frequently, regional and local corporations. The business component is critical—providing internship and mentoring opportunities, which are as important for teachers as for students. Many teachers in advanced subjects find it difficult to keep up with the latest developments without business involvement.

What more do we need to do?

I would look, first, to BEST—Building Engineering and Science Talent, a public-private partnership. BEST recently coordinated three high-level, blue-ribbon panels to identify the best practices for increasing the participation of women, under-represented minorities, and persons with disabilities in science and engineering at three critical points—pre-K-12, higher education, and the workplace.[10] I led the higher education panel. Representatives of several Business Roundtable corporations also participated.

BEST found four guiding principles critical to making a difference:

- **First,** a sustained commitment to change.
- **Second,** integration of diversity into organizational strategy.

- **Third,** management accountability.
- **Fourth,** continuous improvement.

BEST suggests that the federal government create a national-level award program, modeled after the Malcolm Baldrige Award, to encourage innovative practices in building the science and engineering workforce. The Baldrige Award has demonstrated that recognition programs can be powerful incentives for organizational change.

BEST recommends that the science and engineering version should evaluate organizational performance with regard to diversity—based on critical success factors including: institutional leadership and commitment; strategy development and implementation; work systems which enable scientists and engineering employees to achieve high performance; the quality of organizational metrics and systems of accountability; and the levels of job satisfaction for science and engineering workers.

Developing new talent in science and engineering, for global leadership, requires new pedagogy linked to learning styles and to the creation of a new outlook.

We must understand the cognition patterns of students who grew up on VCRs, MTV, video games, and instant messaging, and devise ways of organizing pedagogy to enable them to use their skills and perspectives in yet more creative ways. Information technology can take us beyond classroom walls, offering students the kind of interactive, experiential learning to which they have become habituated, in ways which enhance their analytical abilities and specific knowledge. Simulation of physical phenomena, gaming technology, tele-presence and tele-immersion—the ability of geographically dispersed sites to collaborate in real time—all are pedagogical tools which can help us in this task.

We must educate our students to work between disciplines, reflecting the new and growing multidisciplinarity of research and innovation.

Too often scientific discovery and technological innovation within, and, oftentimes, outside the science and engineering communities are thought of as ends in themselves, or as being divorced from or not directly linked to global issues, except as technical fixes.

But, discoveries and innovations have extensive impacts on the social values of nations, and on geopolitics among nations.

Human embryonic stem cell-based research presents, on the one hand, the promise of medical breakthroughs to arrest disease and alleviate suffering. But on the other, the issue asks a society to evaluate what it means—exactly—to be human.

Developing new talent in science and engineering, for global leadership, requires new pedagogy linked to learning styles and to the creation of a new outlook. We must understand the cognition patterns of students who grew up on VCRs, MTV, video games, and instant messaging, and devise ways of organizing pedagogy to enable them to use their skills and perspectives in yet more creative ways.

During World War I, the British Navy switched from coal to oil. That single change completely altered the British relationship to Middle East nations.

Other social and geopolitical issues reside in human genetics, in environmental science, and more. These are complexities scientists and engineers must be educated to recognize and address, or at least understand.

We now need the leaders of business, industry, academia, and in the policy arena to raise these issues at forums like this one, and with our political leaders. We must refresh the social compact which Vannevar Bush proposed nearly 60 years ago, in his transformational treatise.

We must educate our students to work between disciplines, reflecting the new and growing multi-disciplinarity of research and innovation.

The core idea of the Vannevar Bush model—still relevant today—had three essential elements:

Basic research leads to innovations which are exploitable for our national security and economy, and have positive outcomes for the global economy as a whole.

We do not know from whence the next discovery will arise, but it will arise. Moreover, science and engineering discoveries are inherently multidisciplinary. Therefore, we must support basic research across a broad disciplinary front.

There must be a concomitant investment in human capital development in science and technology, which must be coupled to the support of research itself.

To date, the United States has reaped more benefit than we may realize from our domination in science and engineering research, and from our ability to draw upon global human intellectual capital. This has occurred because we have some unique advantages which have driven our success, including:

- the most sophisticated educational system in the world.
- a well-developed science infrastructure.
- a financial system providing ready access to venture capital and a long tradition of investment in entrepreneurial projects.
- government structures designed to support and invest in the scientific enterprise, and government policies which encourage investment and entrepreneurship.
- a history and tradition of collaboration between the public and the private sector.
- a thriving, diverse culture of risk takers—a culture tailored to innovation, in which a variety of ideas are welcomed and viewpoints sought.
- a long history of taking great risks for great rewards.

But, we cannot rest on these advantages, nor take them for granted. We cannot expect that we will necessarily forever remain THE predominant player in the world. But we must remain A (if not THE) predominant player.

Our robust infrastructure now is being emulated both by developed and developing nations. Those nations, learning from our experience and building upon our successful model, have set their sights on a similar vision—a future overflowing with the fruits of research—for social, economic, and human benefit.

For the first time in more than a century, the United States faces greater—and steadily rising—competition within the global community. To maintain our capacity for scientific discovery, innovation, economic development, and national and global security—to maintain our ability to be a player on the global stage—the United States will have to redouble its commitment and its investments in what has made us the dominant economic, political, and military power in modern times.

To maintain our capacity for scientific discovery, innovation, economic development, and national and global security—to maintain our ability to be a player on the global stage—the United States will have to redouble its commitment and its investments in what has made us the dominant economic, political, and military power in modern times.

We need strong leadership to make this happen—to develop our national will, and to create a national strategy to address the competitiveness of our national science and engineering enterprise. The Council on Competitiveness is undertaking just such an initiative. We need collaborative leadership to make sustainable change across the spectrum of systems including K-12 education, higher education, and the corporate workplace. We need committed leadership to engage governments at each level—federal, regional, state, and local. We need engaged leadership which seeks the talent pool within the new demographics, and finds new ways to ignite the wonder and excitement of discovery in all our youth—to foster their interest in, and commitment to, the challenge of becoming a scientist or an engineer, and to provide the means for them to achieve their dreams.

We need outspoken leadership to inform—both the public and public policy. We live in the information-glut era, where vast amounts of information—some credible, much not—are available at a "click" to everyone. But Internet search engines do not come with "credibility" filters, leaving the public confused, and unenlightened. The resultant sense of disquiet about science, and where it can lead, suggests that we must redouble our efforts to lead and to inform.

The policy, scientific, and corporate communities must join together in formulating science and technology policy. We must not only advocate for the support of fundamental scientific research and investment in human capital, we also must articulate and help to resolve knife edge policy and ethical issues, bringing balance to the debate, and advocating the role science can play in addressing the issues.

We need to look not only at the technical dimensions of public policy, but at the policy dimensions of technological change which springs from basic science.

Public policy is not always—perhaps, not often—an ideal forum for fair debate. It is a roiling marketplace where every voice has its own agenda, and where an issue can become veiled and confused. But, it is a public marketplace for ideas, it is democratic, and it is open. Of course, the public and our political leaders must be willing to listen. There needs to be greater awareness and greater respect for scientists and the role of science in resolving critical national and international issues.

The policy, scientific, and corporate communities must join together in formulating science and technology policy.

We must commit to making the full and best use of our own model. We must commit to investing significantly, competitively, and deeply in a broad range of research areas. We must commit to developing the intellectual capital we must have to continue to implement our unique model and to spread its benefits globally. Our national security and the security of our world rest upon this commitment.

Ours is a history which gives us much to draw upon and which tells us that we did this before, and we can do it again.

Thank You.

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Chapter 3

Question and Answer with Dr. Jackson

QUESTION: The California state legislature's subcommittee for higher education is currently discussing creating more tier one universities. New York State universities perform more tier one research than California universities. So, one sub-discussion of this issue is the need to create more opportunities for universities to perform tier one research. There is a lot of discussion of encouraging more research on a national level. But on the state level it is also an important issue. What are lawmakers doing to encourage the pursuit of such research in state institutions of higher education?

[T]hough there is a need to support basic research across a broad disciplinary front, legislators cannot talk about higher education in isolation. They must look at the entire spectrum of education in this country.

DR. JACKSON: The Council on Competitiveness has been performing studies and holding workshops on innovation for a couple of years now and has been particularly focused on regional innovation models. In fact, recently there was a meeting at Texas A&M under the aegis of this council's National Innovation Initiative. The premise of this initiative both regionally and nationally is supported by what past studies have shown: there are direct links between scientific discovery, technological innovation, and regional economic development. Regional economic development produces new and strengthens existing enterprises. These enterprises in turn help strengthen the United States' global position. There are a number of council publications that discuss both examples of legislative efforts to encourage such beneficial innovative activities.

However, though there is a need to support basic research across a broad disciplinary front, legislators cannot talk about higher education in isolation. They must look at the entire spectrum of education in this country. The students that go to universities arrive via an educational pipeline that runs from Kindergarten through high school. Testing students along the way, as we do now, is not enough. We have to reevaluate who is teaching our children, how they are being taught, what tools are being provided to teachers, and what motivates teachers to enter the profession. Such comments may sound surprising coming from the president of a technological research university. But my university, like the rest, is on the receiving end of what comes out of the educational pipeline. We therefore recognize the need to intervene at an earlier stage.

QUESTION: What model do you use for hiring teachers with backgrounds in math and science?

DR. JACKSON: I am a big believer that particularly at all levels of education, minimally beginning in middle school, we need more discipline based teachers. However, schools are in competition with industry and sometimes universities to attract teachers who are involved in the science and math related disciplines. So I think schools should partner with industry and, as appropriate, with universities to create a cadre of master science teachers. Perhaps an employment contract could be developed that mirrors those held by university professors in science and engineering. Teachers would teach during the academic year and then have industries guarantee them employment during the summer. Such an arrangement would accomplish three things. First, it would elevate the professional status of teachers by linking them with, for example, major technological enterprises; secondly, it would improve the relative incomes of teachers, providing more incentive for qualified individuals to enter the profession; and thirdly, it would keep teachers abreast of the latest developments in their area of expertise.

At all levels of education, minimally beginning in middle school, we need more discipline based teachers.

Information technology and communications networks must also be improved so that, even during the academic year, teachers could be engaged in projects and high-end technological work, just as university professors are. Teachers could work from a distance with their corporate employer and be able to contribute on a more continuous basis to the ongoing work of that company. This would provide an incentive for companies to participate because they would have year-round access to high-end talent. In areas like Dallas or parts of the country where there are scientific enterprises, such as Texas Instruments, it strikes me as a model that is worth trying.

QUESTION: You cited a figure earlier that said China increased the number of doctorates by 5,400 percent. Korea and Taiwan had similarly impressive increases. But is the quality of those degrees on par with those earned from institutions in the United States? And secondly, how did these governments develop the necessary infrastructure to produce so many Ph.D.s?

DR. JACKSON: Over the past decade and probably for even longer, there has been a steady increase in the quality of the graduate programs and of the graduates in many Asian countries. In past decades, these countries would send their students to the United States to be educated. During the 1990s, however, there was a shift, particularly in China. The Chinese government shifted from sending their students to American universities to be educated to encouraging American universities to educate students in China. Thereafter, China was able to develop its own graduate training programs.

The quality of the education is good. A number of my corporate friends are increasingly impressed with the quality of the graduates. As a whole, China is still far from the level of technological development found in the United States and other developed countries, but they are rapidly improving. China's development is largely a function of government intent to create research institutions on par with the tier one universities in the United States. To do this, the Chinese government is augmenting some of their historically strong universities and creating others.

> **In past decades, [Asian] countries would send their students to the United States to be educated. During the 1990s, however, there was a shift, particularly in China. The Chinese government shifted from sending their students to American universities to be educated to encouraging American universities to educate students in China.**

QUESTION: One ongoing concern among government officials and in families across America is the ever-increasing cost of education. Many prospective students simply cannot afford to pay for a college education. What can be done to help prospective students overcome this financial barrier?

DR. JACKSON: First we must understand the realities of the situation and then we must develop new models. There was an article in *The New York Times* yesterday that said that college tuitions weren't increasing as much as people fear because scholarship aid has been increasing at a level that is concomitant with the rise in tuition. Private universities substantially provide need-based aid that—for most students—rises with the rise in tuition. Moreover, a recent study done in New York State indicates that the state's private institutions enroll a higher proportion of students at the lower socioeconomic levels than do public institutions.

Thus, the true cost of attending university and the baseline tuitions for in-state residents are actually relatively low. Moreover, even at institutions where the nominal increases in tuition costs were projected to be large, the base costs from which they were growing was not very high. The best way to help students coming from limited means is to provide more education for them and their families about the various ways to finance higher education.

There are a number of support mechanisms provided by the government, such as Pell Grants, that students have traditionally relied on and that are currently in jeopardy. Similarly, on the state level there are many tuition assistance mechanisms that have been cutback or are threatened with cutbacks.

Nevertheless, no student, even the student who pays the full tuition, pays the full cost of educating him or herself. Universities operate on a model in which some part of their budget is always dependent on the largess of other people. For this reason, fundraising is among the primary responsibilities of any university president, not just to add to the overall endowment base, but also to close the gap between what it actually costs to educate people and what they can pay. That is why I say we must work towards a compact among government, industry, and universities to invest both in the research and the people that develop new transformative technologies.

Chapter 4

The Impact of Federal Funding in Engineering, Computer and Physical Science, and Math

PRESENTED BY

Robert Helms, Ph.D., Dean, University of Texas at Dallas Erik Jonsson School of Engineering and Computer Science

I want to introduce my remarks with my perspective on some recent history. I spent some time in Albany when I was at SEMATECH working on a program with Governor Pataki, IBM, International SEMATECH, and the State University of New York in Albany. In the last 12-18 months, I have been involved in activities that are similar in many ways to those being undertaken in the state of Texas. A significant fraction of those activities focused on finding ways to stimulate research activity regionally.

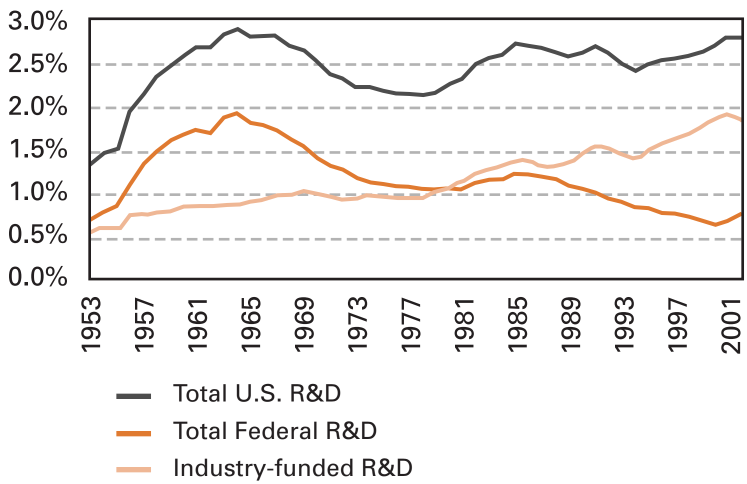
Research, by nature, generally focuses on the graduate schools and on graduate students. So, when I decided to take the plunge back into academia, I remember telling the Dean of Undergraduate Studies at U.T. Dallas, "I really don't have any time for the undergraduate program or K through 12 activities. I need to focus on research and I need to focus on graduate education." That was only 12 months ago, yet I stand before you now and am about to pose three questions, the most important of which relates to Dr. Jackson's point about encouraging young people to become involved in science, math, and technology.

Like many of my generation, including most people in this room, my interest in science and technology was first energized when I saw exciting examples in the media as a child. What inspired me most was probably the space program. Seeing events in space exploration on T.V. each day programmed us, in a sense. It excited our interest and motivated us to stay with science, to stay with math until we had the tools to begin our own explorations of science and technology.

Today's kids can see exciting examples of what technology can do as well. We just had a competition at U.T. Dallas for undergraduate students in our engineering program. Most students participating in the competition decided to focus on robotics—a perfect example of a technology that excites kids. In my experience, environmental sciences and technology also excite today's students.

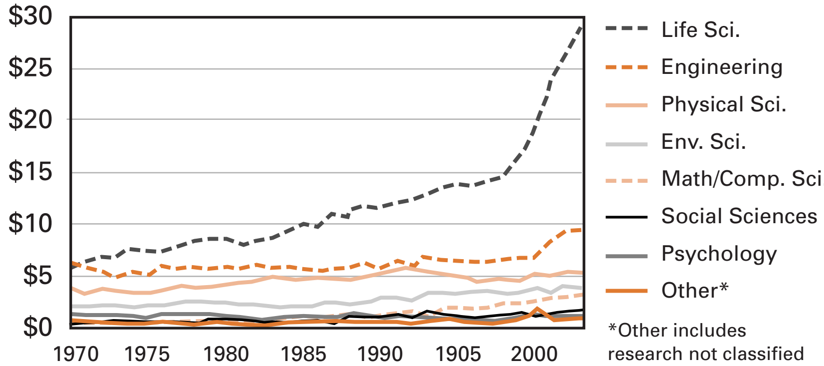
There are some—though fairly few—science and technology subjects that energize young people. What we have to do is get the media to cover these subjects more, so that more children see and are inspired to pursue them. Exciting student interest in just about any science will have effects on the other sciences. Increased levels of space exploration research drove advances in robotics, which in turn drove advances in environmental science and technology. The key to encouraging research and innovation across the scientific and technological spectrum is to get kids jazzed up about science.

R&D Spending as a Percentage of U.S. GDP



This graph focuses on the R&D spending of both the federal government and U.S. industry. What the graph reveals is that over the past 50 years industry has accounted for more and more of the R&D preformed in this country. Moreover, the percentage of federal spending on R&D as a percentage of GDP has dropped an average of two and a half percent per year for the last 30 to 40 years. The last peak was in 1965, the time when the Department of Defense and NASA and the National Science Foundation were doing so much great work on programs like space exploration. Many of the technologies we are just beginning to enjoy today, such as wireless phones and satellite T.V., are the product of developments made during that time period of the 1960s and 1970s.

Trends in Federal Research



*Other includes research not classified (includes basic research and applied research; excludes development and R&D facilities)

Source: National Science Foundation, Federal Funds for Research and Development FY 2001, 2002, and 2003. FY 2002 and 2003 data are preliminary. Constant-dollar conversions based on OMB's GDP deflators. AUGUST '03 © 2003 American Association for the Advancement of Science

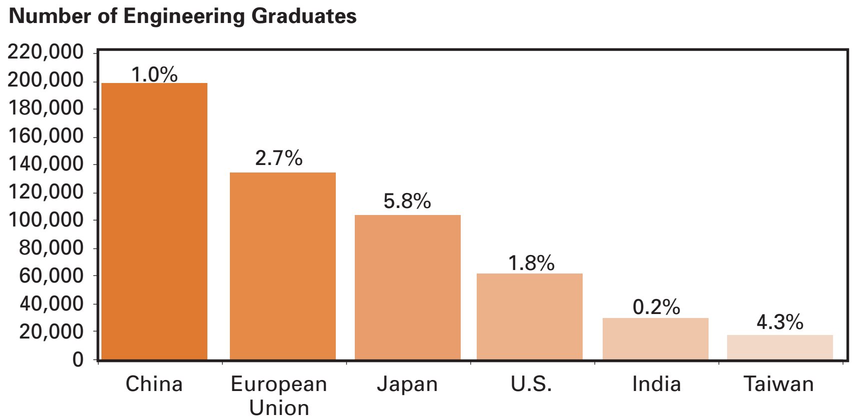
So, if it's true that half the GDP growth of recent years is related to technology and that much of this technology was stimulated by federal R&D spending 30 years ago, what are we going to do to encourage innovation and growth over the next 30 years? Some would argue that industry is picking up the slack. However, industry is in business to increase shareholder value and, in many cases, shareholders may only care about five minutes from now, or, at the most, next week or next quarter. Industry therefore cannot be responsible for researching and developing the technology needed ten years from now. A lot of the fundamental work that was going on in the Bell Labs of the past, IBM's Watson's Labs or TI's Corporate Research Laboratories, is just not happening today, because industry is far more focused on rapid development, not on long-term research.

So, R&D funding has not faired so well over the past decade. The question then is, where is this funding going?

I, like other engineering schools, have bioengineering programs that are funded by the National Institutes of Health. And, though I congratulate my colleagues in the biological sciences for increasing federal funding of the life sciences, their efforts mask the real reduction in federal R&D funding for other sciences, such as engineering, the physical sciences, math, and computer science. Whatever increases there have been, have

[I]f funding to the other sciences is not improved... progress in engineering new materials, such as nanotechnology and information technology will suffer at the basic level.

Nations Outpacing U.S. in Engineering Graduates



% = Percentage of 24 year olds with engineering degrees
Source: National Science Board, "Science and Engineering Indicators - 2002," Appendix Table 2-18

been a function of dollars, not GDP. Increases have thus not been anywhere near enough to keep up with economic growth and even the small rates of inflation that we have had over the last few years.

The life sciences have been the key beneficiary of increased federal government R&D spending. And if funding to the other sciences is not improved, I believe that progress in engineering new materials, such as nanotechnology and information technology will suffer at the basic level.

All the funding that went into the basic sciences during the 1960s and 1970s produced excellent results. We put a man on the moon. We built space shuttles and satellites. Everyday these achievements were on the news and everyday kids were watching—it raised their level of excitement for math and science. These inspired children were a byproduct of that federal funding. I believe having new programs and new ideas in the media is the best way to naturally stimulate the interest of the children who could be this country's future scientists and engineers.

While we're attempting to inspire our children to enter the sciences, other countries are rapidly producing highly qualified scientists and engineers. This graph, which Bob Doering may discuss in greater detail later, displays which countries are generating the most graduates at various levels. It shows that other countries are generating an enormously larger number of engineering degrees than the United States. We are not necessarily in last place in terms of engineering graduates. However, if you were to take a snapshot of 24 year olds and determine what percentage had degrees in engineering, Japan would have almost six percent and China one percent, a number that is growing rapidly. In fact, it may already have overtaken the United States, as this data is a little bit old.

My key point is that, in contrast to the growing number of engineers in other countries, interest in engineering is rapidly declining among American students. The ACT (American College Testing Program) keeps very detailed statistics and information on interest in engineering and their data shows that in the last ten years interest in engineering in high school seniors has dropped by 30 percent in the United States. American kids are simply not energized on the subject. We need to figure out a way to renew their interest so that I can stop worrying about K through 12 and go back to worrying about more research and graduate education.

In a sense, I am talking about marketing. But marketing has to be driven by reality, and must produce results. One thing I definitely know is that kids of my generation were turned on to science and technology because they saw its amazing potential on T.V. and in the movies. If we had a reinvigorated space program, put a platform on the moon or sent someone to Mars, then kids would get really excited and say, "I want to be part of this. I want to be the person in that spacecraft talking to HAL 9000."

The ACT (American College Testing Program)...shows that in the last ten years interest in engineering in high school seniors has dropped by 30 percent in the United States. American kids are simply not energized on the subject.

Chapter 5

Semiconductor Industry Perspective on 'Funding the Foundation'

PRESENTED BY

Robert Doering, Ph.D., Senior Fellow and Technology Strategy Manager, Texas Instruments

The semiconductor industry adds the most value of any of the manufacturing industries that we have in the United States. The high standard of living that we enjoy today in the United States is also based on many different instruments and systems that are enabled by the sophisticated electronics made possible by integrated circuits.

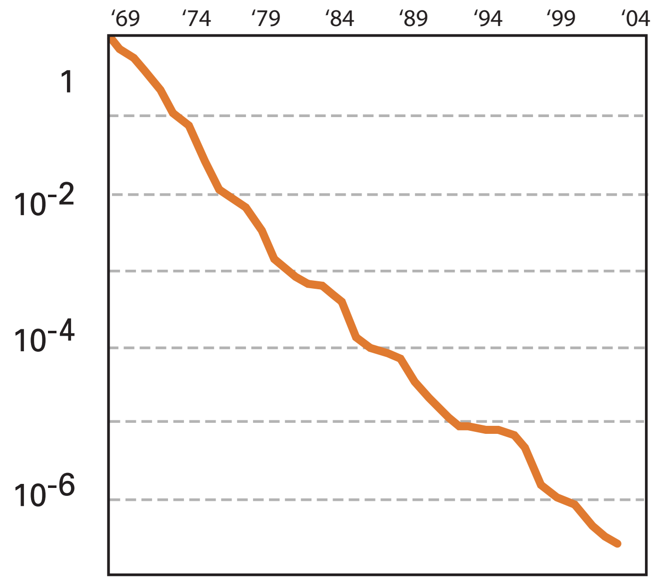
You have just heard two wonderful talks, basically giving an overview of all of the general issues that I can think of related to the topic. So I am going to dive into a narrower slice of the topic, and look in particular at the perspective of the semiconductor industry. I want to talk about the grand challenge of the next 15 or 20 years that will require basic research as its solution, and also identify some of the best sources of information on the overall topic.

The semiconductor industry, to which Dr. Jackson and Dr. Helms alluded, certainly plays a very critical role in this nation's economy. Both speakers mentioned the fact that roughly half of the growth in the nation's GDP has been attributed to growth in productivity from computer and other technologies that are essentially enabled by semiconductor chips, also known as integrated circuits. The semiconductor industry originally made transistors after they were invented at Bell Labs back in 1947. Those transistors were later integrated into assemblies of electronic microcircuits, called integrated circuits, invented by Jack Kilby in 1959.

Certainly, integrated circuits have also strengthened our national defense and security. But, let us take a closer look at how they have enhanced economic growth. The semiconductor industry adds the most value of any of the manufacturing industries that we have in the United States. It creates lots of jobs. The industry currently employs about a quarter of a million people in the United States. These jobs are both high quality and well paying; and we are not trying to export most of them overseas, as you might infer from reading the papers and news magazines. The high standard of living that we enjoy today in the United States is also based on many different instruments and systems that are enabled by the sophisticated electronics made possible by integrated circuits. For example, consider the resulting improvements in medicine, communications, etc. during the four decades since the invention of the integrated circuit. But this exponential progress has been enabled only by a tremendous amount of innovation, most of which was originally funded by the government, and that is, today, increasingly under-funded.

As mentioned earlier, the problem is not that industry is not investing a lot. Of the hundred billion dollars or so that the semiconductor industry will bring into the United States this year, roughly 17 percent will go back into R&D. However, this money mostly goes into technology development for the products that will be introduced over the next few years, not into long-range basic research. Supporting the research that will contribute to continued economic progress in 15 to 20 years is the current challenge.

From Dollars to Microcents (1969–2004) [The Fall in Cost and Increase in Efficiency of a Single Transistor]

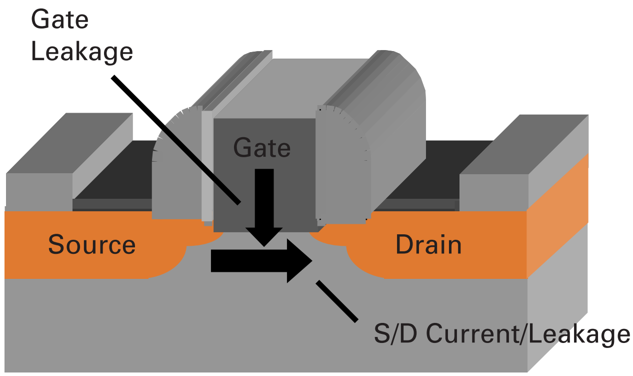


Source: DataQuest, Intel

In a nutshell, I am going to outline the paradigm that has been used for improving integrated circuits over the past four decades. The methodology has essentially been geared towards miniaturization. In the integrated circuits business we refer to it as "scaling," or downscaling the size of a product's features. These efforts have been steadily successful, with linear dimensions being reduced by an average of 0.7 times every two to three years over the history of the industry. Such miniaturization has fundamentally enabled four categories of improvement in integrated circuits. One is increased performance. For example, computer speed has gone from mega-hertz to gigahertz and continues to rise. Such improved performance is facilitated by shrinking circuits; in part, due to the fact that the electrons do not have as far to travel so information can be transmitted faster. There has also been a reduction in the energy required to perform an operation. This has allowed us to use less power for communications and computation, and to create devices such as handheld phones that can be run on batteries. The first mobile phones required massive batteries; of course, today we have cell phones that you can lose in your purse or briefcase if you are not careful.

Another huge advance has been the increase in the number of functions built into a single chip. This can be measured in bits of memory or in the

Basic Limits to CMOS Scaling



number of transistors. More important, however, is the decreased cost of each function. As we have increased the number of transistors on each integrated circuit from dozens, to thousands, to hundreds of millions today, the cost of those transistors has fallen. This graph displays that point. You can see that a transistor in a computing circuit cost about $1.00 back in 1969; today, a smaller, faster, and more energy-efficient transistor costs less than a micro-cent.

This schematic shows what transistors, which compose integrated circuits, look like. The type of transistors used today are called CMOS for 'complementary metal oxide silicon.' This device is basically just a little switch; it can either be 'open' or 'closed.' When it is closed, the current flows through, and by manipulating that switch you control the logic of the integrated circuits. One difficulty, as you continue to shrink these transistors, is that the switch becomes leaky. The contacts get too close together and eventually there is leakage even when the switch is open. This causes too much standby power; even when a device is off, it may then still draw significant power. Another problem is that the cost of making transistors may start increasing as we manufacture more nearly at atomic level precision, which is partly what we are doing today. At this level, just a few atoms here or there make the difference. The requirements for such manufacturing may become prohibitively expensive in the future, unless new technology or methods result from basic research.

Roughly half of the growth in the nation's GDP has been attributed to growth in productivity from computer and other technologies that are essentially enabled by semiconductor chips, also known as integrated circuits.

Now, a lot of people are talking about what the next development after CMOS transistors will be. Before the CMOS transistors, we had bipolar transistors, and before those we had vacuum tubes, which, in turn, were preceded by mechanical relays. Each of these technologies was the switch of its day, allowing the needed calculating or computing to take place.

Today, we have some suggestions for what may follow the CMOS transistor. This chart [on the following page] gives a list of devices that people have been thinking about as possible replacements. The problem is that none of these candidates presently stands up to a risk-reward assessment. Nobody really knows how to make any of these technologies a viable successor to

Possible Successors to CMOS Transistors

Logic Device Technologies	Performance	Architecture Compatible	Stability and Reliability CMOs Compatible	Operate temp	Energy Efficiency	Sensitivity Δ (parameter)	Scalability
ID Structures	2.3/2.2	2.2/2.9	1.9/1.2	2.9/2.9	2.6/2.1	2.6/2.1	2.3/1.6
RSFQ Devices	2.7/3.0	1.9/1.7	2.2/2.8	1.1/2.7	1.6/2.3	1.9/2.8	1.0/2.1
Resonant Tunneling Devices	2.6/2.0	2.1/2.2	2.0/1.4	2.2/2.4	2.4/2.1	1.4/1.4	2.0/2.0
Molecular Devices	1.7/1.3	1.8/1.4	1.6/1.4	2.3/2.4	2.6/1.3	2.0/1.4	2.6/1.3
Spin Transistor	2.2/1.7	1.7/1.6	1.7/1.7	1.6/2.0	2.3/2.1	1.4/1.7	2.0/1.4
SETs	1.1/1.2	1.7/1.2	1.7/1.2	1.2/1.8	2.6/2.0	1.0/1.0	2.1/1.7
QCA Devices	1.4/1.3	1.2/1.1	1.2/1.1	1.2/1.4	2.4/1.7	1.6/1.1	2.0/1.4

Source: 2003 International Technology Roadmap for Semiconductors Assessment of Potential Successors to CMOS Transistor. The values in the table are based on a scale of 1 to 5 with 5 being the highest score possible. They represent the estimated performance capabilities and risk (or likelihood that this device concept can be developed into a commercially viable technology) for each of these candidates for future logic device technology.

CMOS; they either lack the same level of performance or are too expensive.

Finding a viable replacement is not an immediate problem, and will not become a pressing concern next year or in five years or even in ten years from now. By the end of that ten year timeframe, however, we may no longer be able to significantly improve electronics. That time is distant enough that it relates to an earlier point: industrial R&D labs do not put big money into research for ten years down the line. Thus, we really need the federal government to help us with this 10 to 20 year timeframe, so that we can work on replacing the CMOS transistor and improving other aspects of future integrated circuits.

Government Role as Technology Research Funder

Technology	Background/ Infrastructure	Practical Realization	1st Practical Use	Sponsor	Entrant	1st Customer
Telegraph	1801(Voltaic Pile)	1823 (Schilling)	1844 (Morse)	U.S. Govt.	1848 - Magnetic Telegraph Co. 1856 - Western Union	
Radio	1865 (Maxwell)	1888 (Hertz) 1896 (Marconi)	1897 (Marconi)	British Post	1897 – Wireless Telegraph & Signal Co.	British Navy
Vacuum Tube	1884 (Edison Effect)	1904 (Fleming) 1906 (DeForest) – Triode	1907	U.S. Navy	1913 – AT&T	WWI
Solid State Diode	1874 (F. Braun)	1900 (Braun)	1906 1940-Current	AT&T Radar Program	1907 – Pickard Co. 1941 – Thomson-Houston 1942 – AT&T, Sylvania	WWI WWII
Transistor	1923 – 1939	1947 – 1948	1951	AT&T	1951-52 – TI, AT&T, GE, HP, Motorola	DoD
Integrated Circuit	1944 – 1957 (Micromodule Program)	1958 (J. Kilby, R. Noyce)	1961	U.S. Air Force	1961 – TI, Fairchild	NASA DoD
Data Processing		1889 (Hollerith)	1890	U.S. Census Bureau	1896 – Tabulating Machine Co. (From 1917 – IBM)	U.S. Census Bureau
Computer	1841 (Babbage) 1889 (Hollerith)	1945 (ENIAC)	1946 – 1951	DoD	1946 – Eckert-Mauchly Co. (1951 – Remington) 1951 – IBM	U.S. Census Bureau DoCD

Traditionally, the government has helped. The next graph shows the history of technology and electronics and identifies the key roles of the government, either as sponsor or first customer. For the majority of the list, the government has sponsored the research project. When that was not the case, the government was at least the first customer. Each of the products on this chart was the product of a sound, long-range investment strategy on the part of the government. That sort of strategy is exactly what we need again.

The graph on graduate students in sciences has already been discussed today; it shows the very rapid increase in foreign graduate students in engineering, physical sciences, and math. Interestingly, the number of foreign students that are graduating from U.S. universities is part of the yellow line that is declining. The line that is increasing is the red one, which shows the people graduating from foreign graduate schools.

This trend is true also on the level of Bachelor's of Science degrees, which are also very important to our high-tech industries. Many of the quarter million workers in the semiconductor industry in the United States are people with B.S. level engineering degrees. This need for technically-skilled manpower in U.S. industry will continue and mostly needs to be met by a strong source of graduates from our U.S. universities.

Chapter 6

Lockheed Martin Aeronautics Company Interests/Investment in Physical Sciences

PRESENTED BY

John Stratton, Director, New Business Funds and Contracted Research and Development (CRAD) Management, Lockheed Martin Aeronautics Company

I am going to talk primarily about technology research and development. There will be a lot of charts related to the physical sciences, but that is simply because they are very intertwined with my main focus. I am also going to talk about Lockheed Martin Aeronautics Company's research activities.

Lockheed Martin Aeronautics Company has two major lines of business: combat aircraft and air mobility. We have a market segment called C4ISR, which stands for 'command, control, communications, computers, identification, surveillance, and reconnaissance.' C4ISR deals mostly with special mission type aircraft. We have a wide range of products; some of them are existing products on which we make improvements, and others are entirely new.

In general, the research activities that create planes like the F-35 or Joint Strike Fighter, are performed in our Advanced Development Programs. Engineers work on these programs at our headquarters in Palmdale, California, and also in our other sites at Fort Worth, Texas, and Marietta, Georgia.

There are four basic types of research: basic research, applied research, technology demonstrations, and prototype development. We do not perform much basic research directly. Generally, we provide grants or contracts to universities, and establish a non-competitive research relationship with them. We do not compete one university against another for a bid, however, we do compete from a budget standpoint, since we can only allocate funding for a certain number of grants. What we look for is whether a university has a certain technology that we are interested in. We usually come across this sort of information in periodicals or hear about it from individuals who come from that school to work for us.

Lockheed Martin Aeronautics has its own company laboratories. But we also work pretty closely with other laboratories outside of the Lockheed Martin Corporation (i.e., Sandia National Laboratories, General Electric - Global Research Center, etc.) and have various cooperative agreements with them. A lot of research gets accomplished this way.

Nanotechnology is one of the basic research areas where Lockheed Martin is participating. Our primary interest with nanotechnology regards utilizing the molecular structure of the nanotubes for stronger, lighter advanced materials.

Once we have done the basic research, we move on to the applied research stage. At this point, we take what has been developed through basic research and apply it on a small-scale level, relative to our research applications. Sometimes we acquire contracts from the government, depending on what the research involves, that are called 6.2 programs. Of course, our strategic alliances and partnerships also contribute at this stage of development. Issues of materials, such as metals and composites, are addressed at this point.

Next comes technology demonstrations. More contract dollars are needed at this point because the development requirements increase. For example, if we are working on developing a special inlet design for a new aircraft configuration, the inlet size will directly affect the length of the aircraft. However, we also need to be concerned about having enough room around the inlet for proper airflow. Thus, a technology that allows us to compress the inlet could result in a major demonstration. We generally utilize some government contracts to support this, but we also do some of our own research.

After that stage has been completed, our researchers have to develop prototypes. While we have done some of our own prototype work and obviously it is very costly, we also have contracts with the government on major programs where they support the prototype development before signing a major, final contract. The government supported the development of prototypes for the Joint Strike Fighter that I mentioned earlier, for example.

These are the four types of research that Lockheed Martin Aeronautics Company performs. The amount of funding needed increases as research and development progresses.

Some of the areas in which we do research include aero structures manufacturing, signature and survivability integration, mission systems and avionics, product support, aircraft structures design and integration, and aeronautical flight sciences. All of these areas of research and development are interrelated. From a systems engineering perspective, a good design for an aircraft is meaningless if it is not manufacturable. You also need good product support. Research and development therefore cannot be done in isolation; integration across the R&D fields is paramount.

Within these broader research categories there are some smaller areas of focus. Under aero structures design, researchers are also looking at advanced metallics and composites, the materials needed to make the products lighter and less expensive. They are also looking at higher temperature materials for higher MACH number-type aircraft. Throughout the process, manufacturability and cost issues come into play. There is no use developing a design or a prototype if it cannot be produced or is unaffordable to the customer once research has been completed.

Similarly, when our researchers are working on flight science projects, they need to look at issues of aerodynamics and acoustics. In terms of aerodynamics, researchers must look at the lift and drag on the airplane, the shape of the airflow, etc, because these issues directly affect the range and performance of the aircraft. Acoustics are also an important consideration since certain noise levels will do structural damage to various parts of the aircraft. To alleviate these problems, researchers are looking at propulsion integration technologies, such as the special inlet I mentioned earlier. They are also looking at nozzle or vectored thrust where we change the nozzle shape and direction. With all these new systems on the airplane, it is also necessary to discover ways of providing more power and of cooling the electronics systems. So, there is kind of a vicious cycle—for every new technology, other technologies must be developed to support them.

From the manufacturing standpoint, researchers must look at advanced manufacturing processes for composites. In metallics, they have to ask themselves about reliability, and such issues as lowering scrapage rates. Manufacturers also have to think about assembly techniques and reducing the touch labor associated with building an assembly. They must decide whether to use unitized construction or modular assembly or something else. An area of growing concern is energy deposition. There is a strong interest in laser direct manufacturing or electron beam manufacturing, for example.

One important example is a new material, a powdered metal, which can easily be shaped to make various parts. Using this material, a person can actually make a self-contained box out of metal. The idea is to reduce the weight and machine time required to make the desired part. This material, in and of itself, is a very important technology. Eventually, an entire airplane could be made of this; utilizing this technology to make a large aircraft or a large component part would be an extremely important advance.

Another problem that researchers at Lockheed Martin Aeronautics Company are attempting to solve is a means of performing nondestructive inspections. The question is, how do we non-invasively inspect our composites for flaws and damage while in the factory or out in the field? Since prototypes are made differently than the final production articles, advanced prototyping is also an important consideration. Whatever methods our researchers develop must moreover be affordable, so that we can be competitive with other companies.

From a mission systems and avionics perspective, researchers for Lockheed Martin Aeronautics Company are interested in fiber optic networking. Right now we use a lot of coax cabling, which is big and bulky; the wire bundles are huge and run throughout the entire airplane. By using fiber optics, an aircraft can have multiple signals on different optical frequencies. The result is a reduction of the weight and size of wiring. Researchers are also working on making commercial, off-the-shelf hardware more rugged so that it can be used in an aircraft environment, and particularly in fighter planes, which operate under higher temperature conditions. Other research is being done on pilot-vehicle integration, including helmet mounted displays and voice recognition. Voice recognition must be a very subtle technology, since pilots are often in high-stress situations, and speak with different accents—not everyone is from Texas, after all.

Other issues include product support and prognostic health monitoring. On these points, researchers are trying to create systems to inspect, at various intervals, the other systems on the aircraft to ensure that there are no problems. They are trying to develop a way to monitor the system and sense when it is either breaking down or is simply undergoing normal wear. If such issues could be detected, it would reduce the amount of inspections needed. Currently, most inspections are done periodically, without knowing whether something is wrong or what particular part of the aircraft should receive immediate attention. These inspections are done, say, every 500 hours. If they could be done every 1000 hours instead, a lot of money would be saved in terms of support.

Field maintenance versus periodic maintenance is another area of research. There is a big difference in the systems and supplies and equipment that is required for each. Minimizing these differences is important. MEMS, or 'micro electrical mechanical systems,' are very small sensor-type devices that we are trying to embed in a damaged area to monitor the health of the structure and see what, if any, repairs are needed.

From the signature and survivability standpoint, our researchers are looking at special materials, what I would call the radar absorbable materials. Their goal is to integrate these new materials into the aircraft design. New aircrafts have more leeway in their design than conventional ones.

BENEFITS OF INVESTMENTS IN PHYSICAL SCIENCES

Existing Products
• New or Improved Capabilities • Cost Reductions • Increased Performance / Effectiveness
New Products
• Competitive Discriminators • Cost / Weight Reductions • Enhanced Capabilities • Supportability / Reliability Considerations

In terms of directed energy systems, researchers are not only looking at weapon prevention systems and survivability systems, but also at high-power laser or high-power microwaves. Using a laser, for example, a pilot could basically disable a missile that is launched at him.

Those are the general areas that we are trying to cover.

One example that I would like to show you played a major role in our win of the Joint Strike Fighter. We started out with company research in several areas, including composite ducts without fasteners, a bonded-type structure, pre-forms, etc. Using these components, we developed a special inlet design associated with the aircraft and what we call a 'shaft-driven lift fan.' We basically used the engine power to drive the lift fan and the thrust from the engine for lifting purposes. The result is a vertical take-off/landing aircraft. Contracted research was used to build the whole ductwork. Flight test will take this configuration work and actually demonstrate it on an airplane. The result is a demonstration airplane that was further developed into a prototype program. Our prototype included our vertical take-off, or lift fan, technology, which proved very significant. But it required a lot of investment, not just from us, but also from our customer, the U.S. government.

Before closing, I would just like to comment that Lockheed Martin Aeronautics Company uses the physical sciences to the advantage of both existing and new products. In our existing products, we are always being asked to increase or improve their capabilities or, if there is a problem area, to upgrade the product. No matter what the project, we are continually trying to look at ways to reduce costs because we must sell our products, and thus must make them attractive to the customer. These issues are particularly important with our new products, since we must also consider issues of weight reduction, enhanced capabilities, supportability, and reliability. These are all considerations that we look at with our new technologies. Physical science is one of the many different contributing sciences. However, it is also the major driver.

John Stratton used video footage of an airplane's lift-off to the audience to demonstrate his argument.

Chapter 7

Concluding Question and Answer

QUESTION: I would like to make an observation rather than pose a question. The state of Texas has a program called the Advanced Technology and Advanced Research Program. When they had a budget deficit, they dropped the Advanced Research Program, but not the technology program. So despite all the emphasis on basic research, it is often the first thing dropped when a crunchy budget decision must be made. Similarly, when I worked at the National Science Foundation (NSF), I noticed that there was always a lot of pressure on giving big research grants for multimillion-dollar technology prototype demonstrations, and much less importance given to funding basic research. So, even though we talk a lot about the importance of basic research, I think the leadership needs to start placing more emphasis on it.

We have to change our educational system to foster that energy and to focus increasingly on innovation and creativity.

DR. JACKSON: Actually, I think that the presentations today make exactly the sort of case that needs to be made about that point. I think that each speaker essentially said that new technology is dependent on new fundamental research. One difficulty is that many universities may want to treat that basic research as an end in itself. But, if no one links this basic research to societal and global needs, whether that be in terms of defense needs, communications needs, or whatever, then the public will not buy the new technology, and the research cannot continue.

Secondly, when basic research becomes an end in itself, it will never be part of a product that will capture the imagination of people. And, as my colleagues have been saying, capturing the imaginations of people, particularly the young, is very important. I agree with you. I think the need to emphasize basic research has been the point of our discussion today. But this research cannot be conducted in isolation from the needs of the world. That is the other main point.

QUESTION: I graduated with an undergraduate degree in engineering in 1994 and worked in industry for a few years at a manufacturing technology company. After a few years, I began considering my future career prospects and found that getting a business or law degree would be far more lucrative than pursuing a more advanced degree in engineering. As a young engineer, I simply felt that there were insufficient market incentives to stay in engineering.

DEAN HELMS: This is actually a topic that I have thought about quite a bit. I think the problem relates to the issue of outsourcing, and specifically the exportation of high-tech jobs overseas, which we see in the paper almost everyday. From my own experience in the San Francisco area, I think it is increasingly important for us to put more emphasis on the entrepreneurial, innovative, imaginative aspect of tech activity. If I were to look at U.T.D. graduates and try to identify those who will be successful, I would look for those who are entrepreneurs and innovators. A perfect example would be the founders of Yahoo, who were Stanford graduate students at the time I was teaching there. Another example is Cisco Systems, which employs about 1,000 people in Richardson, Texas alone. As with Yahoo, Cisco was founded by two students straight out of Stanford University.

So, my vision is one in which academic institutions focus more and more on getting the kids energized to partake in the sciences. Once this is accomplished, we have to change our educational system to foster that energy and to focus increasingly on innovation and creativity. That way, when students leave their respective universities, they will become the founders of the Ciscos and the Yahoos of the next thirty years. It will not happen for everybody, but I still believe there is enormous potential.

QUESTION: How do you bridge the gap between the need for long-term investment in R&D and the people that control the purse strings, namely the politicians, who have far more interest in the short-term gratification of their constituencies?

DR. JACKSON: In a few weeks I am going to be participating in a program put together by the Science Coalition called "The Breakfast of Champions." The purpose of the program is to recognize members of the Congress who have been champions of supporting basic science. I think it is very important. Now, I am supposed to emcee that event and I am going to ask my colleague here, Bob Doering, to give me that graph (see page 33) that shows how far back various technological advances date and who was supporting that work. I think that chart alone makes a point that needs to be hammered home again and again and again and again.

"[I]f no one links this basic research to societal and global needs… then the public will not buy the new technology, and the research cannot continue.

Secondly, I think that it is very important to capture the imaginations of both politicians and the public with examples. All the graphs in the world about funding curves will not make a difference if the audience is not supportive. The graphs are important for helping us understand where things are, but they do not animate Congress. And so I believe we have to start talking about what matters to people: the War on Terror, for example. Keeping our soldiers alive is important to people. But people have to know how long real advances take, and that is where Bob Doering's chart comes in.

QUESTION: There is a perception, somewhat based on reality, that there is less opportunity today in science and technology. Will this perception deter people from entering these fields, no matter how much we focus on improving S&T education?

It is increasingly important for us to put more emphasis on the entrepreneurial, innovative, imaginative aspect of tech activity. If I were to look at U.T.D. graduates and try to identify those who will be successful, I would look for those who are entrepreneurs and innovators.

DR. JACKSON: I am going to draw on what my colleagues from U.T. Dallas said. I had a thirty second blurb on Lou Dobbs one night a few months ago and he was talking about outsourcing. I made a point similar to one already made that there is a spectrum of tech jobs that ranges from the jobs in a TI to a Lockheed Martin to entrepreneurial activity. And there is a national capacity for such jobs. So, if you are going to make an argument just based on basic job numbers, you will not win. However, if you tie investment in new talent to the development of new enterprises, then you start making a more convincing case.

If you look across the spectrum in the U.S. and ask how many jobs are going offshore and how many jobs are being created or destroyed by this trend, the numbers suggest that the flux is actually net positive for the United States. In the past, the steel industry went offshore, but at the same time new industries were being created, and these new industries created new jobs. We need to recognize that new jobs are being formed, identify what those jobs are, and not worry so much about outsourcing. Outsourcing is, after all, a natural part of the overall global ecosystem in business.

KENT HUGHES: We have had a truly terrific morning. Dr. Jackson very effectively framed the broad challenge that we face in terms of encouraging long term investment in science and technology. Dean Helms emphasized the role that a university can play. And we have explored the link between basic research and commercial success on the one hand, and national security on the other.

Across the panel, everyone has emphasized how critical today's investments are for prosperity 10, 15, 20, and 30 years into the future. That has really laid out a challenge for all of us as we talk to elected officials as well as our colleagues. The "Breakfast of Champions" that Dr. Jackson is attending is a wonderful idea.

I would just like to add one more thing with respect to Bob Doering's slide; it is important to notice that wherever the government was not the inventor it was often AT&T, which is the kind of private sector facility that has largely disappeared. So although the private sector is investing a great deal in research and development, much of the basic research capacity of the private sector has been eliminated. We need to think about how to fill that emerging gap.

Finally, I want to re-emphasize the idea that we cannot focus only on graduate education. As Dean Helms said, K through 12 education is going to be in his future, and in the future of other university administrators. In 1983, a report called "A Nation at Risk" created quite a stir in the Reagan administration and in the country. It became famous for a quote that basically said that if a foreign power had imposed on us our current K through 12 education system, we would have viewed it as an act of war. The sad thing is that with only light editing we could reissue that report today. But our keynote speaker and the panel are undaunted. They have outlined an enormous array of challenges, and at the same time painted a picture of bright opportunity for the future.

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Participant Biographies

FREDERICK M. BUSH is Associate Director of the Woodrow Wilson International Center for Scholars. The former U.S. Ambassador and Commissioner-General to EXPO 92 in Seville, Spain, he has more than three decades of extensive experience in industry, government, and diplomacy. Bush has served in three Presidential administrations, including positions as Assistant Secretary of Commerce for Tourism and Deputy Chief of Staff to Vice President George H. W. Bush. He has worked in both the U.S. Senate and the House of Representatives. In 1993, he was decorated with the Orden del Merito Civil by King Juan Carlos of Spain. Bush earned a B.A. in political science from the University of Colorado and an M.A. in international relations from American University.

ROBERT DOERING is a Senior Fellow and Technology Strategy Manager at Texas Instruments. He is an Institute of Electrical and Electronics Engineers (IEEE) fellow and chairs the Semiconductor Manufacturing Technical Committee of its Electron Devices Society. Doering is also chair of the National Research Council's Board of Assessment for the National Institute of Standards and Technology (NIST) Electronics and Electrical Engineering Laboratory (EEEL). He is on the Technology Strategy Committee of the Semiconductor Industry Association, the Board of Directors of the Semiconductor Research Corporation, and the Corporate Associates Advisory Committee of the American Institute of Physics. He is also one of the two U.S. representatives to the governing committee of the International Technology Roadmap for Semiconductors. Doering has authored and presented over 150 publications and holds 20 U.S. patents. He was formerly a member of the physics department at the University of Virginia. Doering received his Ph.D. in nuclear physics.

ROBERT HELMS is Dean of the Erik Jonsson School of Computer Science and Engineering at the University of Texas at Dallas. He formerly served as president and chief executive officer of SEMATECH. Prior to that, he directed silicon technology research at Texas Instruments and served as corporate vice president. Before joining the private sector, he led research efforts in semiconductor processing and new materials as a professor at Stanford

University. Helms received his M.S. and Ph.D. in electrical engineering from Stanford University and his B.S. in engineering physics from the University of California, Berkeley.

KENT H. HUGHES is Director of the Program on Science, Technology, America and the Global Economy at the Woodrow Wilson International Center for Scholars. He is the author of *Building the Next American Century: The Past and Future of American Competitiveness* (2005 Woodrow Wilson Center Press and Johns Hopkins University Press). He previously served as the associate deputy secretary at the U.S. Department of Commerce, where he worked to define and implement a long-term competitiveness strategy. Before joining the Clinton Administration, Hughes served as president of the Council on Competitiveness. Hughes has also held a number of senior positions with the U.S. Congress, including chief economist to U.S. Senate Majority Leader Robert Byrd, senior economist of the Congressional Joint Economic Committee, and legislative and policy director for U.S. Senator Gary Hart. Hughes holds a Ph.D. in economics from Washington University, a LL.B. from Harvard Law School, and a B.A. in political and economic institutions from Yale University.

SHIRLEY ANN JACKSON, the 18th President of Rensselaer Polytechnic Institute, has held senior leadership positions in government, industry, research, and academe. She is the immediate past president of the American Association for the Advancement of Science (AAAS) and currently chairman of the AAAS Board of Directors, a member of the National Academy of Engineering, a fellow of the American Academy of Arts and Sciences and the American Physical Society, and has advisory roles and involvement in other prestigious national organizations. She serves as a trustee of the Brookings Institution, a life member of the M.I.T Corporation, and a member of the Council on Foreign Relations. She is a member of the Executive Committee of the Council on Competitiveness and serves on the boards of Georgetown University and Rockefeller University. She also serves on the Board of Directors of the New York Stock Exchange, the Board of Regents of the Smithsonian Institution, and is a director of several major corporations. She was appointed chairman of the U.S. Nuclear Regulatory Commission (NRC), 1995-1999, by U.S. President William J. Clinton. At the NRC, she reorganized the agency, and completely revamped its regulatory approach by articulating and moving strongly to risk-informed, performance-based regulation. Prior to that, she was a theoretical physicist at the former AT&T Bell Laboratories and a professor of theoretical physics at Rutgers University. She holds an S.B. in physics and a Ph.D. in theoretical elementary particle physics from the Massachusetts Institute of Technology (M.I.T.), and 32 honorary doctoral degrees.

JOHN STRATTON is Director of New Business Funds and Contracted Research and Development Management (CRAD) for Advanced Development Programs at Lockheed Martin Aeronautics Company. He began his career with General Dynamics' Fort Worth Division, doing extensive work in structural design. He later became involved in conducting both internal research and development and contracted research with the government research laboratories. Stratton was also very active on the teams that helped meld together Lockheed and the Fort Worth division of General Dynamics, and later Lockheed and Martin Marietta. Stratton received a B.S. degree in mechanical engineering from the University of Florida and a master's degree in business management from the University of Dallas.

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GOVERNMENT ROLE AS TECHNOLOGY RESEARCH FUNDER

Technology	Background/ Infrastructure	Practical Realization	1st Practical Use	Sponsor	Entrant	1st Customer
Telegraph	1801(Voltaic Pile)	1823 (Schilling)	1844 (Morse)	U.S. Govt.	1848 - Magnetic Telegraph Co. 1856 - Western Union	
Radio	1865 (Maxwell)	1888 (Hertz) 1896 (Marconi)	1897 (Marconi)	British Post	1897 – Wireless Telegraph & Signal Co.	British Navy
Vacuum Tube	1884 (Edison Effect)	1904 (Fleming) 1906 (DeForest) – Triode	1907	U.S. Navy	1913 – AT&T	WWI
Solid State Diode	1874 (F. Braun)	1900 (Braun)	1906 1940-Current	AT&T Radar Program	1907 – Pickard Co. 1941 – Thomson-Houston 1942 – AT&T, Sylvania	WWI WWII
Transistor	1923 – 1939	1947 – 1948	1951	AT&T	1951-52 – TI, AT&T, GE, HP, Motorola	DoD
Integrated Circuit	1944 – 1957 (Micromodul e Program)	1958 (J. Kilby, R. Noyce)	1961	U.S. Air Force	1961 – TI, Fairchild	NASA DoD
Data Processing		1889 (Hollerith)	1890	U.S. Census Bureau	1896 – Tabulating Machine Co. (From 1917 – IBM)	U.S. Census Bureau
Computer	1841 (Babbage) 1889 (Hollerith)	1945 (ENIAC)	1946 – 1951	DoD	1946 – Eckert-Mauchly Co. (1951 – Remington) 1951 – IBM	U.S. Census Bureau DoCD