Research Universities and the New Era

by Frank Press

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It is a pleasure to participate in this program honoring Mary Anne Fox on the occasion of her installation as Chancellor of North Carolina State University. And it is singularly appropriate that this symposium addresses the future of the research intensive universities — a subject on which Dr. Fox has exercised national leadership with the authority of one who maintains the credentials of a working scientist while serving as a top university administrator. She has influenced policies that will determine the future of American research universities in her multiple roles on the National Science Board and other government agencies, the National Academy of Sciences and on forums across the country. It is certain in my mind that this university under her leadership will serve as a national example of how a research university can contribute to both the intellectual strength and the economic prosperity of our country.

I would like to address the future of the research intensive universities, beginning with a historical context and then offering some guidelines for the decades ahead. I will begin by reminding you of three periods in the history of science and technology policy in the United States. The first corresponds to the period before World War II when the federal government was a minor supporter of science and technology. Most of the nation's research was supported privately and carried out in the universities and a few industrial laboratories. This is the period when Europe was the center of scientific leadership. The United States, by contrast, led in technology and was a dominant industrial power. One might say the United States was the Japan of this period.

The second period is the one that began with the end of World War II and is ending now. Call this the Vannevar Bush Era because his influential report of 1945, Science, The Endless Frontier[1], set the stage. This era, of course, is the one in which most of us have grown up and the one in which world science has been led by the United States. It has been characterized by the federal government's predominant role in the support of fundamental science and engineering in universities and federal laboratories. It also has featured occasional federal support of technology development in areas thought to be important to the nation because of national security concerns. In this period the United States became a world leader both in science and in the creation of new technologies. However, for a period in the 1980s it lost its primacy as an innovator in product design and manufacturing, and has since enjoyed a remarkable recovery. But that is another story.

I believe that we now are about to enter the third era. Call it the post-cold war or the post-Vannevar Bush Era. In this era all the advanced nations will have to compete on a foundation of strength in science and technology, excellence in design and manufacturing, and the training of a technologically literate workforce.

To set the stage let me start with a question. What do the following advances in technology have in common?

- modern agricultural products such as: hybrid crops, mechanical harvesters, and computerized data bases on crop yields
- biotechnology
- designer drugs
- magnetic resonance imaging systems (MRIS)
- penicillin and many other antibiotics

- many important industrial catalysts
- computer numerically controlled machine tools
- digital signal processing (used in communications, exploration for oil, compact discs)
- the stored program computer (the basis for all modern computers)
- Frequency Modulation (FM)
- masers and lasers
- ion implantation (in the manufacture of semiconductor devices)
- computer work stations
- plasma etching
- reduced instruction set computing (RISC)
- artificial intelligence and neural networks
- compilers
- word processing
- image processing
- instrument landing system, loran, inertial guidance
- nuclear energy

The list obviously is an incomplete sample of technological breakthroughs based on fundamental science and engineering. What they have in common is that universities played an important role in their conception, or development, or demonstration, or implementation. All are commercially important today. Many were serendipitous consequences of fundamental research in that the investigator did not anticipate the commercial application, for example lasers and eye surgery or atomic clocks and GPS.

Let me state the obvious: American science and technology are more productive than ever. Incredible advances are occurring in diverse fields. We earn more than our share of scientific citations and accolades. The remarkable progress of science over the last decades of this century presages a new era for science in the decade to come. It will be an era in which the boundaries between basic and applied research erode. More than ever before science will drive technology and technology will accelerate scientific progress. Research-based science and technology of the kind that takes place in universities and some federal laboratories has been and will be a major factor in the economic growth of the United States. Other advanced nations recognize our success and aspire to a similar future and are moving to emulate our research universities, and our decentralized, competitively based research funding system.

What I have in mind includes not only fields with obvious applications, like computer sciences and material sciences, but others that we usually think of as being removed from the marketplace. For example, astronomy, practiced almost exclusively in universities. Although individual astronomers are largely motivated by intellectual curiosity and the search for new knowledge (and that's enough), nevertheless, they also are pioneering the use of advanced sensors. Astronomers are designing systems to acquire huge data bases that can be stored and transmitted in compact form and made accessible to large numbers of remote users. These activities have important practical applications such as transmitting data from satellites that monitor Earth's environment.

Or consider plant biology whose scientists have found plants with genes that produce natural pesticides, anti-tumor drugs, anti-viral agents, and other valuable chemicals. (I remind you that eight or nine of the largest products in biotechnology to date involved a collaboration with a university laboratory.)

Still another example is mathematics. It usually is considered one of the purest of academic research fields. But a recent report of our National Research Council lists the important contributions that mathematics research has made to five key industries: aircraft, semiconductors and computers, petroleum, automobiles, and telecommunications.[2]

And every successful executive in the information technology industry between Silicon Valley and the Research Triangle will tell you that this great American success story would not have been possible without the contributions of research and training by the computer science, electrical engineering, and mathematics departments of our research universities.

It has been 45 years since Vannevar Bush advanced his rationale for federal support of science. Remember what Bush said: "The scientist doing basic research may not be at all interested in the practical applications of his work, yet further progress of industrial development would eventually stagnate if basic scientific research were long neglected." But even so omniscient a statement as that needs to be re-examined against the events of our times, just as we constantly interpret our nation's constitution.

I believe today's world provides an even greater clarity and new emphasis to Vannevar Bush's statement than ever before. The new reality will be an even more direct connection between fundamental science and engineering as practiced in universities and their social and commercial applications. I would describe the situation this way. In the years ahead, many nations will strive for economic growth. They also will improve their use of technology. That's as it should be. Let us hope it will not be a zero sum game and many nations will prosper. However, each nation has to find its own route to economic success. For the United States our comparative advantage will be leadership in research and training in fundamental science and engineering.

We can see the beginnings even today. The sample list at the beginning of this paper is the 20th century prologue to a 21st century paradigm in which new knowledge will be the currency of successful industry. Today's unprecedented rate of discovery in almost every field of fundamental science and engineering is resulting in more rapid spillovers to industrial applications. A current example, cited by Edward Penhoet, CEO of Chiron Corporation, is the fact that a third of all U.S. biotech companies, that means a third of all the companies in the world because almost all are in the United States, are located within thirty five miles of a UC campus. No accident!

What is new in this phenomenon is the speed with which all of this is occurring. It reflects a shortening of the time from discovery to application in a growing number of fields such as biotechnology, microelectronics, materials, and computers. Another aspect of the new dynamic between science and commercial technology is the changing attitudes of university scientists. A few decades ago, scientists and their students at universities were not particularly receptive to industrial contacts. Government agencies did not encourage cooperative research between federal laboratories and industry. Scientists feared that a push for commercial market relevance would distort the nature of research both in content and in the allocation of funds.

The research environment is changing today, however, as these sectors pursue collaborative relationships with enthusiasm. And if I am right about a future in which the boundaries between basic and applied research fade, commercial relevance will be an intrinsic feature if not a stated goal of most of science. So, too, for social benefits such as fighting disease or improving the environment. As a result, with relevance so widespread and unpredictable, the test for relevance of any particular field of science should become less important in assigning funding priorities. An event of great symbolism occurred a few years ago when industrial scientists at IBM won Nobel Prizes in physics two years in a row for basic research with commercial relevance. The awards signaled the merging of the basic and applied research cultures.

What does this shift mean for the research universities? What does it mean for technological innovation and economic growth?

Today's more powerful link between scientific leadership, economic security, and quality of life will provide the new impetus and rationale for the support of the research intensive universities in the post-Vannevar Bush Era, just as the valuable military contributions of science gave Bush and his colleagues the standing to launch the current era of federal support of science.

As we prepare policies for the future we should remember that technological innovation derives to a large degree from two major sources. One is called the cyclic process. By that I mean incremental improvement in product or process technologies. Repeated incremental improvements are a process that Ralph Gomory and Roland Schmitt have described in *Science Magazine* as "always doing a little better than the other guy".[3]

Gomory and Schmitt pointed out that "incremental improvement has given us better resolution and quieter and better quality printers each year. It has given us jet engines with double the thrust-per-unit weight of three decades ago." There are many examples that can be added to this list — for example, consumer electronics, automobiles, and civilian aircraft. All are characterized not by breakthroughs but by improving the design of products and the way they are made. Sony's co-founder Akio Morita put it this way:[4] "Look at the case of the Walkman. Many have called it an innovation marvel, but where is the technology? Frankly it did not contain any breakthrough technology. Its success was built on product planning and marketing." In recent years, many American firms have learned to become good at frequent incremental improvements of their products and more efficient production — factors in the remarkable resurgence of the American economy.

The other route to innovation is through what can be called research-based technologies. These are breakthrough technologies stemming from research in fundamental science or engineering. The transistor is a prime example. It came out of solid state physics and opened the computer age and the information revolution. Biotechnology is another example. It came out of molecular biology and the laboratories of the research universities supported by grants from the National Institutes of Health.

I believe that a fundamental feature of the of the decades ahead will be the ascendancy of these research technologies that are seeded in advances in fundamental research rather than in refinements of existing processes and products. That is where we already are strong because of our research university system. And I believe it represents our best chance for future our prosperity and for stimulating the economies of other nations as well.

Let me share with you a list of emerging research-based technologies that will begin contributing to economic growth by the end of this decade. The list was prepared by The National Institute of Standards and Technology of the Department of Commerce[5] a few years ago. It should be updated by adding technologies such as flat displays, nanotechnologies, biocompatible materials, biochips, biosensors, and other examples but it still illustrates my point. The twelve technologies in four categories on the list all show special promise. I particularly like this selection because it was based on interviews with U.S. practitioners drawn from the private sector rather than the government. The 12 technologies stem from basic science and engineering research and can be described as more than science opportunities but less than ready for the market. They require more research, technological development, and preparation for manufacturing in order to realize their full potential.

The technologies, shown in the slides, break down into four groups: life sciences, materials, electronics and information systems, and manufacturing systems. They draw from much of the fundamental science and engineering research carried out at universities and a few federal laboratories. By the year 2000 they are expected to generate annual U.S. sales of $350 billion. The worldwide projection is $1 trillion in sales.

Even these immense figures fail to capture the true economic impact. Advanced materials, for example, are predicted to have annual U.S. sales of $155 billion in the year 2000. But they also will be essential to innovation in diverse other industries such as electronics, automobiles, aviation, construction, appliances, and machine tools. The collective worldwide sales total many trillions of dollars. In other words, the capacity of these emerging technologies to leverage economic growth across the industrial spectrum, both high-tech and low-tech, is enormous.

Table 1. The Emerging Technologies

Emerging Technology	*Major Technology Elements*
EMERGING MATERIALS	
Advanced Materials	Structural and Functional Ceramics, Ceramic and Metal Matrix Composites, Intermetallic and Lightweight Alloys, Advanced Polymers, Surface-Modified Materials, Diamond Thin Films, Membranes, Biomaterials
Superconductors	High-Temperature Ceramic Conductors, Advanced Low-Temperature Conductors
EMERGING ELECTRONICS AND INFORMATION SYSTEMS	
Advanced Semiconductor Devices	Silicon, Compound Semiconductors (GaAs), ULSI, Memory Chips, X-ray Lithography
Digital Imaging Technology	High Definition Systems, HDTV, Large Displays, Data Compression, Image Processing
High-Density Data Storage	High-Density Magnetic Storage, Magneto-Optical Storage
High-Performance Computing	Modular/Transportable Software, Numerical Simulation, Neural Networks
Optoelectronics	Integrated Optical Circuitry, Optical Fibers, Optical Computing, Solid-State Lasers, Optical Sensors
EMERGING MANUFACTURING SYSTEMS	
Artificial Intelligence	Intelligent Machines, Intelligent Processing of Materials and Chemicals, Expert Systems
Flexible Computer-Integrated Manufacturing	CAD, CAE, CALS, CAM, CIM, FMS, PDES, Integrated Control Architectures, Adaptive-Process Control
Sensor Technology	Active/Passive Sensors, Feedback and Process Control, Nondestructive Evaluation, Industrial and Atmospheric Environmental Monitoring & Control
EMERGING LIFE SCIENCE APPLICATIONS	
Biotechnology	Bioprocessing, Drug Design, Genetic Engineering, Bioelectronics
Medical Devices and Diagnostics	Cellular-Level Sensors, Medical Imaging, In-Vitro and In-Vivo Analysis, Targeted Pharmaceuticals, Fiber Optic Probes

Our traditional excellence in basic science and fundamental engineering research as practiced in our research universities enable us more than any other nation to take advantage of emerging technologies and to harvest the wealth they create.

Examples that I mentioned earlier, such as biotechnology, materials, and computers, demonstrate that universities make important economic contributions in return for the investments made in them. U.S. universities also have provided the nation with the world's largest and best-trained force of scientists and engineers.

[Legislators often ask me why they should fund research rather than social needs. The other needs are legitimate. Indeed, there are homeless people living within a block of this auditorium. We must do what we can to meet the nation's social needs. But the United States lacks the resources to do everything. In order to do more, it must create new wealth by enhancing its economic performance. The research universities are essential to this process, and I might add, also in social progress, such as curing diseases and protecting the environment.]

I began my address by recalling how Vannevar Bush laid out a plan for American science following World War II. His vision sustained science and the nation for more than forty years. Today I have forecast a future for our country in which the research universities play a key role. C.P. Snow said that "scientists have the future in their bones." This is more true than ever as we enter a new millennium in which our future will depend heavily on what goes on this campus and the other great research universities.

NOTES

1. Vannevar Bush, *Science the Endless Frontier: A Report to the President on a Program for Postwar Scientific Research*, 1945. Reprinted by the National Science Foundation, 1990.

2. *Mathematical Sciences, Technology, and Economic Competitiveness*, National Academy Press, 1991.

3. Ralph Gomory and Roland Schmitt, "Science and Product," *Science*, VOL. 240, NO. 4856, 1988, pp. 1131 *ff*.

4. Akio Morita, The First United Kingdom Innovation Lecture, Royal Society and Fellowship of Engineering, London, February 6, 1992.

5. U.S. Department of Commerce, Technology Administration, *Emerging Technologies: A Survey of Technical and Economic Opportunities*, Washington, D.C., 1991. Source: Technical knowledge of the staff of the U.S. Department of Commerce, in particular of scientists and engineers of the National Institute of Standards and Technology. Based on interviews with U.S. international science, engineering, and industrial experts.

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