

NEW WAYS OF LOOKING AT US SCIENCE AND TECHNOLOGY

For 50 years Federal science policy was rooted in cold war perceptions of a world in which the US had one military rival and virtually no scientific and technological equals. The nation must redirect science and technology to objectives that sustain social progress and economic growth while preserving our planetary habitat.

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It is curious how I have gained a reputation as a curmudgeonly commentator on science and technology issues. I like to think that the term "curmudgeon" is inappropriate, because I believe I'm just more outspoken and possibly more realistic than most self-appointed gurus in the embattled field of science and technology policy. So to maintain my status, I will stick my neck out to speculate on some trends and patterns in science and technology as well as in higher education.

To place my remarks in context, let me state my conviction that America's world dominance in science and technology since World War II is no accident. It has its roots in the cold war, in which the US had only one military rival and virtually no scientific and technological equals. I return to the cold war era not to bore you with clichés but to argue that what is past is often prologue—that we are not fully aware of the profound and continuing impact of the cold war on our thinking and on our institutions.

World War II and the arms race that followed created a siege mentality in America's psyche and precepts, which contributed to the way we planned and practiced both our national and our personal lives for five decades. For all those years the nation's great science and technological enterprise was influenced pervasively by the cold war. It still is.

In his excellent account of scientific research at MIT and Stanford during the cold war,¹ Stuart Leslie, a historian of science at Johns Hopkins University, cites a 1946 memorandum from General Dwight D. Eisenhower. Years before he entered politics, Eisenhower commented in his memo on the significance of science and technology in World War II: "The lessons of the last war are clear. The armed forces could not have won the war alone. Scientists

and businessmen contributed techniques and weapons which enabled us to outwit and overwhelm the enemy. Their understanding of the army's needs made possible the highest degree of cooperation. This pattern of integration must be translated into a peacetime counterpart which will not merely familiarize the army with the progress made in science and industry, but draw into our planning for national security all the civilian resources which can contribute to the defense of the country."

This pervasive "integration" of civilian resources with military needs escalated throughout the cold war, and today that 50-year heritage is hard to relinquish. We have lost the ability to see other perspectives from which we might structure our goals and efforts. Indeed, since 1945 America's impressive science and technology enterprise has been forged in this framework. Research for the military produced some truly wonderful discoveries and applications. Two huge industries that come close to defining our contemporary society—aerospace technologies and electronics and computers—emerged from research and development supported by the Defense Department. Through the 1950s, the Pentagon supported nearly 80% of all Federal research and development, and in most years of the 1980s military spending accounted for about 65% of Federal R&D.

The political justification for military R&D was the "external threat" of the cold war. But there were other benefits: bigger budgets for university science, better research facilities and even a few Nobel Prizes. In addition, the Defense Department conceived and developed Arpanet as a backup communications system in the event that our domestic telephone system was sabotaged or destroyed. Named after the Pentagon's Advanced Research Projects Agency, Arpanet begat today's Internet system. In fact, by supporting research in semiconductors, supercomputers and software, ARPA is often credited with shaping commercial computer technology. Also, lest we forget, national defense paved the way for our interstate highway system, and the Soviet challenge in the post-sputnik space race launched our first nationwide initiative in pre-college science and math education under the banner of the

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National Defense Education Act of 1958.

Looking backward, we need to acknowledge the Pentagon's farsightedness in supporting, through ARPA, the Office of Naval Research and the Air Force Office of Scientific Research, extremely basic research in materials, mathematics, oceanography, acoustics, lasers and optics—research that has progressed beyond the military's core mission and resulted in many new products and services.

From our current perspective, it is hard to envision what we might have done differently. In his book, Leslie comments on this myopia: "No one now can go back to the beginning of the cold war and follow those paths not taken. No one can assert with any confidence exactly where a science and engineering driven by other assumptions and priorities would have taken us. . . . While the 'benefits' of the military-industrial-academic complex have been amply demonstrated in successive generations of sophisticated weapons systems, so have the costs, in an American science and engineering dominated by the same mindset that made those weapons possible in the first place. Breaking out of that mindset will take time, determination and not least of all money—money that will be exceptionally hard to come by."

I have quoted Leslie to underscore an important point: If, as a society, we are to have any hope of unshackling our thinking from past paradigms, we must first perceive those paradigms as objective landscapes rather than obliviously perpetuating them as the very structure of our thought.

I came upon a similar proposition while reading the most recent PHYSICS TODAY roundtable (March 1994, page 30). In it, Mark Myers, senior vice president for corporate research and technology at the Xerox Corporation, says quite correctly: "The growth in R&D funding that we have witnessed over the past 50 years—starting with the publication of Vannevar Bush's *Science—The Endless Frontier*—was at a rate greater than the increase in the GNP. It was driven largely by the military needs of the cold war. In fact, the environment for R&D was an open loop: The more you created, the better off you were not to use it. In that environment, it's sociologically and psychologically difficult to say enough is enough. Now, in a commercially driven environment, the paradigm for evaluating R&D funding is vastly different. People make decisions about what is enough in a way different than they do in ensuring the nation's defense. The scientific process will remain the same now that the cold war is over, but I think the relationship to the social contract written by Vannevar Bush will be different. In this paradigm, it's hard for me to envision that it will grow at the rate that it has in the past."

There is no question that national security has served as the primary rationale for a rapid expansion of our research system as well as for much of our institutional thinking throughout the Federal government, as Myers suggests. As we contemplate new national goals and a new role for science in fostering those goals, we need to admit that while the cold war riveted our attention to both real and imagined Soviet threats, it diverted our attention from serious perils at home. Many domestic problems—economic, political and social—have become increasingly intractable. The disintegration of our communities, the changing nature of family structure, the plague of violence, the disappearance of high-wage, high-

value jobs, the deterioration of our environment, the proliferating disparities between the rich and the poor, the absence of affordable health care and the growing popular discontent with our system of political governance are just the beginning of a new agenda for the next 50 years, to which scientific research must be directed as effectively as it has been to military defense over the past 50 years.

Just as scientists considered themselves duty-bound to apply their knowledge and skills to the national interest during the cold war, they need to work for a better America now and in the future. The new task will not be as simple

as perhaps it first appears. In fact, I consider it a moral imperative to enlist science and technology in a campaign for a more productive and humane soci-

ety in which all Americans can enjoy the benefits of an improved quality of life.

To begin moving in this direction, we must look at issues and problems in a new way. Although the country's economic prosperity has been a consistent and commanding concern throughout our history, from now on economics and environmental concerns will be increasingly integrated. We will not be able to consider one without the other. In the past, not only have our economic goals been disconnected from our environmental objectives but they frequently have been in conflict with them. With the need to couple economics and environment, we should conceptualize a science and technology agenda that moves us in the direction of sustainable development—a life pattern that promotes economic and social survivability while preserving the planetary habitat that supports such activity.

For our industrial and commercial activities, sustainable development is conceptualized by the term "industrial ecology." The rubric of industrial ecology encompasses the integration of economics, technology and environment. In the not-too-distant past, changes in business to improve profitability were driven by technology and by economics. In the future those changes will be driven by technology, economics and environmental concerns.

Industrial ecology, like pollution prevention, is anticipatory. Where industrial ecology works, it precludes the need for remedial solutions by preventing problems and pollution throughout the entire production process. Instead of treating the symptom of a problem, it addresses the source of the problem. The economic paradigm in which the environment is expendable and cost-free (sometimes called the Tragedy of the Commons) will give way to the economic pattern of prevention and preservation. I have used the phrase "economic pattern" and not "environmental pattern" because the goal is for prevention to be integrated into lifestyle, industry and commerce in a way that will eventually become the new paradigm for our society.

The development of new materials will be particularly important to the achievement of industrial ecology. Several years ago Merton Flemings and Joel P. Clark, both professors of materials science and engineering at MIT, wrote² that "a fundamental reversal in the relationship between humans and materials is taking place. Its economic consequences are likely to be profound. Historically, humans have adapted such natural materials as stone, wood, clay, vegetable fiber, and animal tissue to economic uses. The smelting of metals and the production of glass represented a refinement of this relationship. Yet it is only recently that advances in the theoretical under-

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Techie talk: President Clinton invited the author to the White House on 16 November to discuss science policy issues. Conversation topics included the research and technology budget, reactions to the death of the Superconducting Super Collider and Congressman Brown's visit to Russian space facilities that would be useful to any US-Russian collaboration on a space station.

standing of structural and biologic material, in experimental technique, and in processing technology have made it possible to start with a need and then develop a material to meet it, atom by atom."

As we begin to grapple with ways to achieve our economic objectives without betraying our environmental goals, we will rely increasingly on the design and development of new materials to bridge the accomplishment of those twin needs.

Another critical component in the economic-environmental model will be new approaches to energy development and use. In 1973, as a result of the Arab oil embargo, we began a hue and cry to lessen the national dependence on imported oil. Now, some 20 years later, pollution prevention must become the guiding principle of our energy agenda. In terms of energy resources, we are only beginning the transition from fossil fuels.

In those past 20 years the Federal government has introduced many energy policies and programs, but few have had much influence on transportation. Currently we have initiatives for increased mass transit, for intelligent highways and for safer, more efficient, clean cars. But while such efforts are improvements, they focus on the trees and not the forest. We must begin to think and act beyond short-term so-called solutions and to envision new work models that minimize or eliminate commuting to work. "Telecommuting" strategies as well as community-based workstation centers that house interactive information systems need to become part of our energy planning.

Particular long-term social benefits could result from such a change in our lifestyle. If large numbers of people did not leave their homes to work, there is every likelihood that community life in America would be reinvigorated. In the past our communities provided the social support infrastructure that we now look to government to pay for and provide. The growing phenomenon of commuting has led to the abandonment of our communities. A telecommuting model could reestablish many of us in our localities while enabling us to work worldwide.

The disintegration of community life is just one indication of a need for more emphasis on the social sciences in this new era. An enhanced social science knowledge base is required if we are to have the insight and perspective that are needed to rebuild those communities, understand the dynamic of healthy family structure better, diminish the incidence of violence, cope with the growing

automation in our lives and nurture a morality and ethic based on self-esteem and human dignity.

In health care too we are at the threshold of major changes. *The Economist*, a respected British newsmagazine, recently published a special feature on the future of medicine.³ It argued that "there is, surprisingly, little or no evidence that modern doctors, pills or surgery have improved people's overall state of health. The increase in Americans' average life expectancy from 63 years in 1940 to 76 today has been ascribed more to increased wealth, better sanitation, nutrition, and housing, and the widespread introduction of the refrigerator than to modern medicine. In 1992 the World Health Organization concluded that the world's population is not getting any healthier. The WHO study showed that people are reporting more frequent and longer-lasting episodes of serious and acute illness than they did 60 years ago."

Science and technology have played an increasingly pervasive and expensive role in America's medical system—a system rooted in remediation. In the future, we are likely to experience changes in medical practice from remediation to prevention. The adoption of preventive medicine will be accompanied by acceptance of the principle that individuals are largely responsible for maintaining their own health.

This shift in the practice of medicine raises major questions: How will technology be marshaled for delivering preventive care? Can medical technology become really cost-effective? Should we expect changes in the role of basic research in the biomedical and life sciences? I firmly believe that such questions must be addressed by our citizens as informed voters and by the health-care establishment. In addition, with much more than biomedical concerns at stake, the entire scientific community, not just the biomedical contingent, needs to share in answering these questions. Because health care is so central to the national quality of life and because it represents such a large fraction of our economy—and will continue to do so no matter how the delivery of health services is finally structured—our decisions at this crossroads will have a serious impact on our long-term future.

At the global level, we already see a trend toward internationalizing "big science." In fact, we should go beyond this by assimilating the developing nations into the framework of this international structure, as we already do in the many areas of "small science." For both

big science and small science (and such terms are largely artificial distinctions) an enhanced and more effective regime of international cooperation can have many benefits in developing countries, such as enlarging the number of capable scientists and engineers, improving the production and distribution of technology, increasing economic growth and diffusing new cultural paradigms, including that of sustainable development.

The demise of the Superconducting Super Collider made it increasingly apparent that if the US wants to support big science in the post-cold-war world, we need to do it through international collaborations. Genuine international partnerships mean shared costs, shared designs, shared responsibilities, shared management and shared recognition.

Except during periods of world war and regional upheaval there is, to be sure, a free flow of information in the international research community. In fact, it is generally accepted that the results of basic research are a public good open to all who want them and would make use of them. This suggests that big science endeavors ought not to be marketed to policymakers as panaceas for domestic economic problems or as commercial bonanzas. It also suggests that politicians ought not to peddle such projects with false or faulty premises either.

I recently proposed a set of initiatives that I hope will shift the US focus in big science from one limited to domestic opportunities and resources to one based on international opportunities and resources. What is required is essentially a new partnership.

As a first-order requirement to help ensure sustained Congressional commitment, all research projects in excess of \$100 million would be authorized in legislation by Congress. Such authorizations would be based on non-partisan, objective evaluations of the project's design, construction, use, cost and timetable for completion. Besides informing Congress and the taxpayers of what to expect, the examination and the subsequent authorization or lack of one would give prospective foreign collaborators a good idea of our expectations, either rosy or otherwise.

Second, the President's science adviser would be required to compile a report that identifies promising areas of science that need a sustained commitment like the current global climate change initiative or a particle accelerator laboratory. The report also should provide details of plans by other countries to pursue similar projects or build similar facilities and should evaluate the potential for international collaboration in such ventures.

Third, we need to think in terms of establishing an international panel among the G7 nations to develop global priorities and funding sources for big science projects. In addition, developing nations, or individual researchers from those nations, should be welcomed as participants even if their governments do not help finance the particular project. The goal should be to enlist the broadest knowledge and expertise to achieve the optimum results, and also to attract the widest participation to ensure broad dissemination of the knowledge gained, especially to countries trying to enhance their indigenous science and technology capabilities.

While we need to bring developing nations into the sustainable development framework, there is great danger here for industrial nations to misinterpret the needs of other nations in terms of their own parochial goals. There

is a risk that the meaning of sustainable development will be distorted so that each nation sustains its current standard of living. Obviously, poor nations are not interested in sustaining poverty.

On the other hand, to replicate today's models for economic development in the industrialized nations around the globe would require 10 times more fossil fuel and 200 times more mineral wealth, with concomitant environmental impact. An equally grim outlook: If past patterns of development continue in the poor nations, then the already staggering number of 1.2 billion people living in absolute poverty would multiply drastically.

There is no question that new models for economic development that are more than symbolic are needed both here and abroad. The programs must produce economic and cultural growth, but not for the few at the expense of the many or for any of us at the expense of the environment, which comes at the expense of all.

If we think that sustainable development is only about protecting the environment, we will be deceived by our own tunnel vision. In 1983, the secretary-general of the United Nations appointed a commission, led by Gro Harlem Brundtland, Norway's prime minister, to propose political and environmental strategies for achieving greater cooperation among countries at different stages of economic and social development. In her foreword to the commission's report,⁴ Brundtland appealed to governments, citizens' groups, educational institutions, industrial organizations and the scientific community to help direct the world "onto sustainable development paths in laying the groundwork for our common future." To the commission, sustainable development "demands a careful balance between the compulsions of today and the needs of tomorrow, between private initiative and public action, between individual greed and social compassion." The report goes on to say: "The next few decades are crucial. The time has come to break out of past patterns. Attempts to maintain social and ecological stability through old approaches to development and environmental protection will increase instability. Security must be sought through change."

It is here that scientists and technologists can be so critical—for example, in developing safe, efficient, environmentally sound and economically acceptable energy systems and in making sure that outer space, like international waters, remains a peaceful domain for the benefit of all, not for exploitation by a few.

This approach will require a new perspective both domestically and in our foreign policy.

As we relinquish the constraints and assumptions dictated by the cold war over our institutions and our national life, we must ask what this new era portends for and requires from all of us in general, and what it means for our

system of higher education and academic research in particular.

Almost a thousand years ago, it was the universities that provided the important impetus for the Renaissance. John Masefield, an English poet laureate, said it plainly in a speech at the university of Sheffield on 25 June 1946: "There are few things more enduring than a university. . . . For century after century the university will continue, and the stream of life will pass through it, and the thinker and the seeker will be bound together in the undying cause of bringing thought into the world."

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Many credit the durability of universities to an ability to evolve and adapt. Indeed, the American university broke with the European tradition in the latter part of the last century by introducing the unique integration of teaching and research. The American style of democracy and equality came to higher education at the end of World War II, when the government paid for veterans to attend colleges and universities under the GI Bill. No longer were higher education and the opportunities it opened the province of a privileged few.

To cite *The Economist* again,⁵ this time on the subject of universities: "Thirty years ago, universities were arguably the most pampered institutions on Earth. Governments showered them with money, convinced that they were engines of growth and agents of equality. Intellectuals lavished them with praise, calculating that they were instruments of enlightenment and sources of largesse. And clever graduates, beguiled by the prospect of being paid to think, and sometimes teach, provided them with a ready supply of talent."

Despite the acerbic tone, this description is not far from the truth—some 30 years ago. In the last few years, however, universities have been struggling with a far different reality. They are being buffeted by two forces on a collision course: rising costs and declining revenues. This situation is causing a major reassessment of roles, responsibilities and priorities.

The economic crisis is not unique to American universities. In Britain and Germany, universities are also in the throes of turmoil. In both countries the national government plays a far greater role in university operation than in the US, where, since the Morrill Act of 1862, a partnership between the Federal government and the states has provided higher-educational opportunities unparalleled in world history.

Today there is another opportunity for stirring change. Most colleges and universities, both private and public, will need to come to grips with the nation's rapidly changing ethnic and socioeconomic demographics. In addition, the advent of widespread interactive instruction needs to become an integral part of higher education. In the telecommunications era, site-specific campuses may become an anachronism. "Virtual universities" can arise just as "virtual corporations" are now emerging. The world is indeed a global village. Even so, universities have remained entrenched national institutions. The fact that they attract students and scholars from around the globe hasn't really changed old strategies of teaching and research.

How will the changes in society affect the research enterprise? Over the last half-century we have achieved spectacular scientific and engineering accomplishments in the service of a society threatened by external forces. Now we must be attentive to Leslie's reminder that "no one can assert with any confidence exactly where a science and engineering driven by other assumptions and priorities would have taken us."

A science and technology enterprise driven by the priorities of a humane society will surely concern itself with goals different from the ones that were dominant in the past 50 years—those enunciated by Bush in *Science—the Endless Frontier*. The new goals will direct us toward a society in which work is meaningful, families are secure, and children are well nourished and well educated; where prevention is the first line of defense in health care; where

the environment is respected and protected for future generations; and where sustainable development becomes the conscience of our progress.

This new agenda, by its very nature, will upset the status quo in our research system and in many of our institutions. This is as it should be. We must have a

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research system that arches, bends and evolves with society's goals. Many compelling goals for science, technology and society are ex-

pressed in the Clinton Administration's white paper "Science in the National Interest."

Lest you think only politicians are talking in such terms, the comments of David Goodstein, vice provost and professor of physics at Caltech, should dispel that notion. In a paper presented to the Sigma Xi Forum on Ethics, Values and the Promise of Science on 25 February 1993, Goodstein expressed the belief that we are at "the beginnings of the end of the exponential expansion era of science." He suggests that scientists "are still trying to maintain a social structure of science (research, education, funding, institutions, and so on) that is based on the unexamined assumption that the future will be just like the past. Since this is impossible, I believe we have some very interesting times ahead of us."

The creativity and intellectual vigor of the entire science community will be needed to achieve a redirection. This talented community must help define and initiate the change. Its members cannot stand by anxiously or stubbornly hoping to avoid the inevitable.

As a cautionary note, American business and industry are right in the middle of their own restructuring. The good news is that these changes will enhance their ability to compete and prosper. The bad news is that they are coming to the task some 20 years late because of stubbornness and complacency.

If the science community can heed that lesson and see the forthcoming changes not as adversity but as opportunity, then the community's collective intelligence and ingenuity cannot help but assemble a research system that is more successful and responsive than the one currently in place.

Times of transition are disquieting. They disturb the status quo but also offer rare opportunities to reshape the landscape. Robert Kennedy once said: "Progress is a nice word. But change is its motivator and change has its enemies." The challenges we confront suggest opportunities to influence the future in unique ways. My view of the opportunities for science and technology in the US fills even this curmudgeon with encouragement and excitement.

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This article is adapted from a talk delivered at Yale University on 29 April 1994.

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