PART 4

The Year 2000 ± 25: Retrospective and Prospective Views of Science and Technology Policy

In 1976, the AAAS held its first Colloquium on R&D in the Federal Budget to examine the strengths and limitations of federal budget planning for R&D. In the subsequent 25 years, the meeting has grown to establish itself as the major public meeting in the U.S. on science and technology policy issues. Part 4 of the *Yearbook* recognizes the dual occasions of the arrival of the new millennium, and the celebration of the Colloquium's silver anniversary with six reflections and predictions about S&T policy. The following chapters touch upon the lessons we have learned from the previous quarter century and suggestions for improvements to S&T policy for the next.

In Chapter 7, Christopher T. Hill of George Mason University discusses what he believes are some recurring themes in S&T policy. Included in these themes are problems associated with the allocation of scarce funds across fields and institutions; ensuring the integrity of scientific and technical knowledge; and improving the public's understanding of science. He writes, "The problems appearing under these enduring themes are never solved. They recur repeatedly in slightly different forms, and each generation of policymakers has to address them anew." Another concern he addresses is the lack of an applied research organization to address critical national problems such as computer and information security issues. According to Hill, "We desperately need to get research underway to understand the issues that develop as the Internet becomes part of our daily lives."

William B. Bonvillian, legislative director for Senator Joseph Lieberman (D-CT), contributes Chapter 8. He proposes that the economy will be the next force to which science will attach itself to "for nurture and support." Since innovation is the current driver of the economy, R&D has grown in importance. However, Bonvillian sees a problem: while businesses have begun to invest more in development, they are not doing enough research. Moreover, he holds that while industry is supporting the life sciences it has de-emphasizing the physical sciences. This places the physical science in an awkward position: "For research support they will continue to depend on government support; to tie to development, they will have to integrate more effectively with industry."

In Chapter 9, Susan E. Cozzens of the Georgia Institute of Technology provides a prospective look at S&T policy over the next 25 years, with an emphasis on the type of world she wants to leave for future generations. She embraces a global perspective of the issue, and closely ties science and technology policy to world peace. Cozzens hopes that future generations will see the a world that "is not dramatically different from the one we have now, but one that has evolved in a humane direction." Her vision of the future includes an "educated and empowered" world that has a "better distribution of comfort."

In his second contribution in this *Yearbook,* Michael M. Crow of Columbia University writes about the societal outcomes of scientific research. He opens Chapter 10 with a rebuke: "Despite great advances during this century, science and technology have failed to address some of the most critical existing and emerging needs of society." He suggests that we have outgrown the assumptions that science is always a force for human good, and that societal good can arise from the "amalgamation of the results of individual scientific projects." Instead, Crow proposes that we restructure the research portfolio to distribute equally the benefits and moderate the social cost of technological change.

Former director of the White House Office of Science and Technology Policy, Neal Lane is the author of Chapter 11. In his paper, Lane echoes the themes regarding science and society expressed in previous chapters, stating, "The accelerating pace of discovery generates a sense of even greater urgency to ensure that this accumulated knowledge is used to create opportunities for society and to make this next 100 years a great 'century of opportunity' as well." He speaks directly to the issues Bill Joy raised in Part 3, suggesting that we need to travel the "visionary path," while ensuring that our science and technology is humane and appropriate.

Part 4 closes with Newt Gingrich former speaker of the House of Representatives. Gingrich believes that we are in an "Age of Transitions" in which nanoscience, biology, and information will create capabilities that were unimaginable 50 years ago. He warns however, that if advancement is to occur at its current pace, an opportunities-based science budget will need to be implemented. According to Gingrich, "If we do not make the investment in the initial discovery, our capacity to create economic growth industries, to lead the world in these products, and to save more lives could all disintegrate within a decade." He concludes by reminding us that today's economy is based upon the science of the past two generations, while tomorrow's economy will be based upon the science of today.

7 Fifty Years of Science and Technology Policy in Ten Minutes

Christopher T. Hill

This chapter takes a quick look at the past 25 years of science and technology policy issues in order to try to say something coherent about the next 25.

I will begin with a few recurring themes in science and technology policy over the past 25 years. These themes hold considerable promise for defining the agenda of the AAAS Colloquium on Science and Technology Policy when it meets 25 years from now (in the year 2025). I will then speculate about some specific topics that could be on the agenda in 2025. I will conclude with a suggestion for the agenda for 2001.

Recurring Themes

First, a key enduring theme is allocating scarce funds across fields, problems, and types of performing institutions. This theme is closely related to the theme of interagency coordination of research activities and to the theme of setting priorities for science.

A second enduring theme is ensuring the integrity of the corpus of scientific and technical knowledge. This includes specific issues like the adequacy and functioning of the peer-review system; managing fraud in science; and dealing with pseudo-science, junk science, and, most important, self-delusion in science.

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Another perennial theme is enhancing access to science for everyone, along with improving public understanding of science. This is both a continuing problem and a continuing opportunity.

Yet another recurring theme is balancing the essential openness of the scientific system with the critical protection of strategic scientific and technical assets. This emerged as a serious issue during World War II and continued throughout the Cold War. Today, the specifics have changed but the theme is the same: balancing the openness of the university with the need for corporate control of information in a competitive world based on new technology, taking advantage of the networked society while ensuring that information assets can be protected.

The problems appearing under these enduring themes are never solved. They recur repeatedly in slightly different forms, and each generation of policymakers has to address them anew. They are the endemic issues that define the essential nature of what science and technology policy is, both as a field of inquiry and as a field of practice.

The 2025 Agenda

Since only the specifics of these perennial issues change (while their fundamental character remains the same), I can predict with reasonable assurance some of the main themes of the 2025 AAAS Colloquium on Science and Technology Policy. These themes will be familiar: allocating scarce resources and setting national priorities, ensuring the integrity of science, enhancing access to science for all, and balancing openness with the protection of strategic assets. I can not imagine that these problems will go away, and we could have a session on any one of them in 1976, 2000, or 2025.

I will now offer some more speculative suggestions of issues that might be on the agenda in 2025. One subject for the 2025 agenda might be, "What's Next for the National Aeronautics and Space Administration (NASA)?" By 2025, we will probably have sent people to Mars and returned them safely. "What's next?" has been the perennial NASA question since we went to the Moon in 1969. I expect it will come up again after our trip to Mars, with all the attendant anguish that this question always raises.

New directions for medical and health care research will also be on the agenda. We will be focusing more on lessons from social science research to learn how to manage the growing numbers of the very old—those 110 and older.

Another topic for 2025 will be the debates in Congress over repealing the last remnants of obsolete 20th century legislation protecting personal privacy. Everyone at the 2025 AAAS Colloquium will wonder at the naivete of the folks in 2000 who tried to strengthen privacy protection in the face of the emerging ubiquitous Internet. By 2025, there will be nothing private left to protect. Everyone will know or be able to find out anything at all about anyone at all.

By 2025, and perhaps well before that, officials from the National Institute of Mental Health will be on the agenda to discuss their new programs of research on Internet depression. This syndrome will have been identified as resulting from the collapse of the fantasies that, in the Internet era, everyone is connected to everyone else and everyone is in control of himself or herself. We will have discovered that neither fantasy is or can be true—that connection with everyone lies beyond human cognitive powers, and that networked information systems can be used as well for centralized as for individualized control. Mental health research and practice will face a whole new set of challenges that are unlikely to be addressed successfully by chemical means.

In 2025, finding money in the federal budget for research is going to be a real challenge. We will, of course, have the cost of supporting all those 110-year-olds. And we will have to make enormous investments in our energy-conserving infrastructure and in the means to manage the effects of global warming. The big story in Congress will be the tremendous cost of the Great American Coastal Seawall that we will be building from Boston, Massachusetts, to Brownsville, Texas, to hold back the rising ocean.

Finally, the centerpiece of the 2025 Colloquium will be the reports of progress on the frantic efforts in university and government laboratories around the world to locate the source of that three-day burst of coherent radiation that originated beyond the solar system, and reached us in late 2024. It included the proofs of all of Euclid's geometry. Where did the signal come from and how can we connect to those who sent it?

The 2001 Agenda

I would like to return from my predictions for 2025, to end on a more serious observation about the immediate future. One of the things that has struck me over the past 25 years is the number of times that we have needed a research and development program to address a critical national problem and we have not had an appropriate place to put it. We have made numerous attempts to create such a place, but without long-term success. For example, in the late 1960s and early 1970s, the National Science Foundation created, first, IRPOS (Interdisciplinary Research on Problems of Our Society) and, later, RANN (Research Applied to National Needs). In the 1980s there was interest in creating a "civilian DARPA" (Defense Advanced Research Projects Agency). Also, in the 1980s, Representative George Brown, Jr. (D-CA) was interested in a National Technology Foundation. In the early 1990s, we set up the Critical Technologies Institute, which was intended to tell us what the emerging needs were, if not where the relevant research could get done. But we still do not have any place to go.

Why is the lack of an applied research organization a problem? Let me give some examples of the sorts of issues it might address. Today, computer and information security is an example of a critical national problem for which there is no home for research. Academic scientists and engineers have no place to go for support for research on this problem. Another important "homeless" research issue is understanding and managing the societal effects of the Internet. We desperately need to get research underway to understand the issues that will develop as the Internet becomes more a part of our daily lives. But there is no place to go for support for such research.

We have needed a national applied research organization for a long time. In the 1950s, we needed a place to fund research on desalinization of water. In the 1960s, the problems were developing new methods of housing construction and upgrading the technology of mature industries. In the 1980s, the problem was dealing with inefficient manufacturing systems. Fortunately, the people who did the studies leading to the book, *The Machine That Changed the World*[1], found support at the Sloan Foundation and in the auto industry itself. Without that support and their study, American manufacturing would not have enjoyed its present resurgence. The government was nearly absent in the support of studies and research to improve our manufacturing systems.

Throughout the last 50 years, we have not been able to create an enduring operation that can identify and seriously support research applied to the emerging problems of our society. Addressing this key issue ought to be high on the science and technology policy agenda of the new President and the new Congress, and it should be a cornerstone of the agenda for the AAAS Colloquium on Science and Technology Policy in 2001.

Endnote

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8 Science and the Economy

William B. Bonvillian

For 60 years the story of science largely has been the story of the relationship between science and national defense. Science began coming into its own at the middle of the 19th century. Initially science thought it could stand alone as a separate and higher discipline in society, almost a separate religion, with an identity all its own. While science was grappling with this separatist ideology, the dominant story of the 20th century was the shift in conflict from nation state against nation state to conflict between competing supranational ideologies. Science, for all its earnest hopes at the outset of the century to remain aloof and above the fray, was instead swept into it, becoming a critical tool in supranational conflict. Now that kind of conflict, too, has been swept away. We are now confronting the problem of identifying the next great underlying force science will attach itself to for nurture and support. The answer, I think, is obvious—the economy.

The 19th century romantic view of science would have it return to aloofness, to its own separate, religious base. This is unrealistic. Science and society are in a symbiotic relationship, feeding on each other. We might think it nice if science could return to the ideal of the isolated medieval university (which in turn descended from the isolated monastery). But just as the academy is increasingly a center of the economy's well being, science will also be attached to the great forces that affect the well being of society. Indeed, it is part of those forces.

William B. Bonvillian is legislative director for Senator Joseph Lieberman (D-CT). This article is based on remarks delivered at the 25th Anniversary AAAS Colloquium on Science and Technology Policy, held April 11–13, 2000, in Washington, DC.

The New Direction of the Economy Means a New Direction for Science

If science is going to be ever more intimately attached to the economy, we need to examine the forces that are moving the economy. Our whole economic policy agenda is shifting. We see a move from current productivity dominating economic analysis to innovation now dominating economic policy.

If innovation drives business organization, then science, the innovation force, will have to be more closely integrated with business for the well being of both. "Science trickle-down," the theory at the heart of Vannevar Bush's 1940s pipeline model of separate, disconnected steps of innovation, will increasingly be replaced by "connected science," where science is integrated into an innovation continuum.

R&D Investment Levels by Government and Industry

If innovation is king of the economy, research and development (R&D) investment levels become critical. Overall R&D investment levels look excellent. The National Science Foundation (NSF) tells us that:

> As a percent of Gross Domestic Product (GDP), R&D last year was at 2.8 percent (up from 2.67 percent in 1998), the highest level since that great heyday, the mid-1960s (when we had a hot war, a cold war, and a space race to sponsor R&D).[1]

NSF data also tell us that business has been stepping up to the R&D plate:

> U.S. R&D expenditures have steadily increased. Between 1995 and 1999, the average yearly growth rate was 6.1 percent, about triple the inflation rate. For 1999, the R&D growth number looks like eight percent. The growth in our R&D rate is due to the private sector. Business is now outspending government on R&D by more than two-to-one. This is an historic reversal of roles. In the 1960s and 1970s the federal government completely dominated R&D, outspending the private sector two-to-one.[2]

Fixing the Problems of the 1970s and 1980s

These numbers show us something about the private-sector role in science. First, they show us that the business role in R&D is growing by leaps and bounds. This underscores my point about science being allied to the economy in the next half century.

Second, they suggest that business is pursuing the problem we had in the 1970s and 1980s. That was a period of the lowest economic growth in U.S. history. Growth was locked in the two percent range and productivity gains were alarmingly dismal. This meant a constant risk of inflation every time growth inched up, which in turn forced caps on growth through interest rates that set the cost of capital. Literature from that era speaks about our failure to capitalize on our research base and create new products.

We saw a disconnect known as the "Valley of Death" between research and development in the economic sector in the 1970s–80s. There was a great connection between research and development in the defense sector, because so much of science, especially physical science, was funded by defense. (This intimate connection between research and defense was exposed to the world in the lightning campaign of Desert Storm in Kuwait and Iraq, for example.) The federal investment level in research was high through the 1970s as measured by percent of GDP. But the connection in the private sector between research and development was a serious problem. Put another way, we had R and D (Research and Defense) but not R and E (Research and the Economy).

The accelerating business investment in R&D in recent years is an attempt to tackle this problem. If one of the New Economy realities, as I mentioned above, is that innovation rules, R&D is crucial. Business, with major new R&D investment, may be tackling the connection between R and D, a most critical economic connection. The booming economy seems proof. We may never have had in our history the productivity growth we had during the first quarter of 2000: over six percent. Treasury Secretary Lawrence Summers suggested we focus on this level of six percent.[3] Economists in 1992 would have suggested this might be either the inflation level or the unemployment level, but they never would have suggested that six percent would be the sum of the inflation and unemployment rates. And 1992 economists could not conceive that six percent would be the productivity growth level.

But in the New Economy you have to get behind the macro numbers and get to the micro. The gross label "R&D" doesn't cover what business really does. Business does not do R, it does D. Because it was not doing D in the 1970s and 1980s, it was not able to move on the federal government's investment in R, so we had limited innovation and stunted growth. Now business appears to have woken up. It's spending on D in a way it never has before.

This spending is largely limited to three areas: computing, the Internet, and bio-pharmaceuticals. Our economy is working its way through these three interrelated technology revolutions. Each is at least as powerful to the economy as past technology shifts(for example, railroads, electricity, radio, and aircraft.) The current pattern appears to be that science contributes a breakthrough technology or batch of technologies and then the economy, over time, piles application after application on top of each. It is the accelerated pace of innovation and its acceptance that seems to be the most important characteristic of what economists are calling the New Economy.[4] (Perhaps it should really be called the Innovation Economy.) Accelerated R&D patterns are not the only innovation components of this economy. Venture capital and entrepreneurship are other elements in the emerging innovation system. But R&D is the crucial initial phase.

The gross private-sector numbers on investment in development indicate that we're making progress on the problems of the 1970s and 1980s. We can use the analogy of a seesaw. From the 1960s until the 1980s, the level of the federal investment on research was on the high end of the seesaw, but the level of the private-sector investment on development was on the low end. There was an imbalance and, in the emerging innovation economy with a focus on R&D, low development meant economic trouble. But change was on the way.

The R&D Seesaw Goes the Other Way

Amid the current economic euphoria, I am concerned that while we may have partly fixed one part of the seesaw (the D side), the seesaw is now tilting in the other direction. We're working on the D, but now we've got a problem with the R.

Total federal R&D (which means predominantly R, because the federal government funds the earlier stages of this equation) went down significantly in the mid-1980s through the mid-1990s.[5] This was in large part due to the post-Cold War decline in defense R&D.[6] This year, for a change, the prospects look somewhat better. The Administration, spurred in part by the Senate-passed R&D doubling bill (S.296), has submitted a budget with significant science increases. Although the Congressional Budget Resolution cuts that back significantly, there are reasonable prospects for the final numbers.[7]

We need to look at two trends. First, I believe that the real number to look at is the federal research share of GDP. This number shows in a way clearer than the annual numbers what the real investment level is, what the ongoing commitment to science is in the national economy. That number trend is continuing to stagnate or decline, and is far lower than it was in the 1960s or 1970s. While federal research was 1.8 percent of GDP in the mid-1960s, it is now 0.8 percent, despite the Innovation Economy's need for higher investment levels.[8]

Second, looking behind the appropriations totals for FY 2000, we see an imbalance within the federal research portfolio.[9] The life sciences have made their case for federal support and have assembled a very effective lobbying effort, which includes companies, medical schools, and grassroots patient groups. They are getting strong increases: 14 percent in FY 2000 and a comparable number anticipated this year. These increases are masking the cuts in the physical sciences, which largely result from declining defense research. Physics has had a 20 percent cut, electrical engineering a 30 percent cut, chemistry a ten percent cut, and mathematics a 20 percent cut, measured from 1993 to 1997.[10] Even President Clinton has decried this physical-life science imbalance.[11] The physical sciences have mounted no advocacy effort comparable with that of the life sciences.

So the seesaw is going out of balance in the other direction from the 1970s and 1980s: D is up and R, in the physical sciences, is down. This R imbalance is a problem science is going to have to address. A white paper from the Semiconductor Industry Association summarizes the seesaw problem well:

> A critical component of the foundation for the U.S. technology-based economy is our knowledge of the physical sciences and engineering. Our ability to produce the incredible advances of the 20th century, such as the transistor, the laser, the microchip, etc., rest on our understanding of the basic sciences of the material world. Basic research is primarily funded by the federal government. Therefore, as federal investment in the physical sciences and

> engineering declines, the future foundation for these disciplines is being weakened. What are the consequences of uneven funding? The attraction of these fields for university researchers declines, new discoveries in the more neglected fields shrink, and graduate students drift to other fields and departments.[12]

Industry Support for R *and* D in the Life and Physical Sciences

There is a fundamental difference between defense support for science (the story of the last 60 years) and private-sector support for science. The defense sector supported both Research *and* Development. Although I believe that the future ally of science will be the economy, only in the life sciences/bio-pharmaceutical areas does industry significantly support R as well as D. Support is not there yet for physical science research.

The life sciences provide an interesting model for the physical sciences. First, industry and academia are much more closely integrated in the life sciences than in the physical sciences. While academic medical research even a decade ago treated drug companies like "Upstairs/Downstairs," that attitude is gone. The biotech firms brought academics into business, and dual careers with frequent movement between business and the academy are now common. This integration has helped the life sciences obtain major increases in federal research support, as well as growing industry support.

Second, in the life sciences, capital has been available for research. Even though the U.S. venture capital industry historically refuses to finance research, and will fund development only if it is no more than three years from product manufacturing, biotech broke that rule and obtained financing for a wide range of research projects that were 10-to-15 years away from manufacturing. The race between public- and private-sector researchers over resolution of the human genome suggests how the line between fundamental and applied R&D is being erased in the life sciences. Part of that is accounted for by the power of intellectual property protection in the life sciences. A patent that ensures 17 years of monopoly rents, coupled with a certification from the Food and Drug Administration that ensures immediate market acceptance, can be compelling in commanding long-term capital. Perhaps because problems in the physical sciences have a wider variety of solutions, monopoly rents have been less accessible and patents have not been as powerful there yet.

So the "Valley of Death" between R and D remains very real in the physical sciences, even as it is being bridged in the life sciences. This means that the physical sciences will have to ride two horses. For research support they will continue to depend on government support; to tie to development, they will have to integrate more effectively with industry. These are the two major tasks confronting the physical sciences:

- rebuilding federal research support, including in the defense sector, and

- building new bridges to industry development support.

There will be no *deus ex machina* here to rescue physical science. No new force is likely to descend to fix the research imbalance. Physical science is going to have to make its own case, just as life science is now effectively making its case to the public and Congress.

Accommodation Between Business and Science

Let's suppose that physical science begins to catch up with life science and rebuilds federal support, and then it begins to create "connected science" with industry. The accommodation with industry, as recent experiences in the life sciences suggest, will not be easy.

As dependent on innovation as business is becoming, there is still a Tower of Babel language problem with science. While business speaks a language of trade secrets, science depends on open knowledge; while business seeks competitive advantage, science has a tradition of open inquiry. A recent polemic in *Atlantic Monthly* titled "The Kept University" (see chapter 26) illustrates the problem.[13]

We should remember that the accommodation between defense and science has always been uneasy, however profound the alliance was for science. Illustrative of this is J. Robert Oppenheimer's reaction to the initial atomic bomb explosions, that ". . . the physicists have known sin."

Science needs to be realistic, however. The isolated academy is simply not a likely prospect for this century. Science needs to go into its growing relationship with the economy with its eyes open, and develop rules and guidelines for research with industry. Many research universities are already working some of these issues out, and the life sciences, where integration with the private sector is already deep, will provide the initial tests. The science societies need to monitor these experiments and circulate results and models.

In a recent article, Professors Robert Rycroft of the George Washington University, and Donald Kash of George Mason University suggest there may be a positive ending to this story.[14] They argue that technologically complex products will increasingly dominate the world economy, which will require complex innovation. Innovation cannot be dominated by single firms in closed systems any more. Instead, groups of firms will have to collaborate across industries, as well as with research institutions. The speed of innovation will require self-assembled networks of researchers in industry and academia, across numerous fields, interacting, assembling, and reassembling. In other words, even as global competition in market economies increases, business will have to evolve a model of collaborative research that is inherently open. We already see the growth of such cooperation. It bodes well for a relationship between science and the economy if open inquiry also becomes an economic imperative.

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9 A Prospective Look at Science and Technology Policy

Susan E. Cozzens

For those of us born in 1950, the millennial propensity to look backward and forward takes on special meaning. We are passing our half-century mark just at the time the world is passing its own important milestone. When I look back over a half century in science policy, I notice some striking trends. First, the science and engineering enterprises have grown enormously, now surpassing the wildest dreams of the founders of science and technology (S&T) policy in terms of numbers and funding. Second, the atmosphere of stability and trust in which the relationship between universities and government began has largely been maintained, despite some difficult times. It has even extended beyond research universities to more educational institutions on the one hand, and beyond the federal government to state governments on the other. Third, universities themselves have evolved significantly and are now more open and interdependent with their environments than ever before, with a greater range of partners playing an ever greater role on campus. Fourth, we have seen a gradual but steady decline in the dominance of global military force as a context for research, and a steady rise of global business as the most relevant environmental factor. These trends form a plausibility framework for the points I want to make about the future.

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Those of us who have the job of looking forward have the luxury of not only describing what has been and what is, but also what we want to bring into being. In addition, I challenge us to think outside our usual boxes and to consider directions for our enterprise, rather than the details.

I fully intend to be around 25 years from now, still coming to the AAAS Colloquium on Science and Technology Policy. But by that time the world will no longer be mine. Instead, it will belong to my daughter, who is now 20, and to her generation. They will be in full swing by then, shaping a world they will pass on, in turn, to their children. What kind of world do I want my daughter living in 25 years hence? What kind of world do I want my grandchildren to inherit? What roles will science and technology policy play in setting the character of their worlds? These are the questions I will address. Some elements of the world I want for them are not particularly related to S&T policy, but other elements are very much in the hands of the people who decide the direction of S&T policy.

First and foremost, I want my grandchildren to live in a world that respects people. I want their world to appreciate differences and to celebrate many cultures, many histories, and many learning styles. I want it to welcome the contributions of all races and both genders. These points are fundamental. They do not refer to areas that we typically see as influenced in particular by S&T policy, but certainly they represent areas where we in science and engineering have lots of work to do within our own institutions.

Second, I want my grandchildren to live in a world where prosperity is shared—or at least shared more broadly than it is now. S&T policy has a direct role to play here. We in the science and engineering community often see ourselves as the creators of prosperity through our roles in innovation and economic growth. But we do not often think about the disparity that growth is creating between rich and poor people and rich and poor nations. We must remember that in the developed world, about five percent of the population lives in extreme poverty—some in our own towns and cities. We must also remember Latin America and East Asia, where 20 percent live in such poverty, and Africa and South Asia, where 40 percent do. The economic growth of the North can create not only disparity, but indeed despair, in nations and communities that see no hope of catching up. We often do not think of our research agendas in this global context, and thus do not let ourselves see how skewed they are to the problems and issues of the developed world. Yet it would take so little to redirect some of our enormous research energy to the pressing health and food problems of the world's poor, rather than the sophisticated medical demands and high-tech consumption needs of the world's affluent.

Third, I want my grandchildren to live in a world free of war—or at least freer than it is now. Science and technology policy bears directly on the probability that this will be so. One invisible reason for the enormous growth and productivity of the U.S. research enterprise over the last half-century is that we have been a country at war abroad but in peace at home. We have not had war on our soil. Although we have lost sons and daughters in several military confrontations over these decades, our homes and our laboratories have been safe. Most of the world cannot say the same. Over the past five decades dozens of local armed conflicts, mostly civil wars, have killed nearly as many people combined as World War II did. Military governments have been in control in many countries. In these nations, our fellow scientists have been jailed and some have disappeared completely. It is only when we forget this global context that we take our peace and democracy for granted.

Peace and war are elements of the future that are very closely related to S&T policy. This is where the trends I noted above hold out so much hope. For my grandchildren, let me put these hopes into words:

- Let the global economy expand.

- Let nations and leaders continue to learn how much they have to lose and how little they have to gain from armed conflict.

- Let us increase our ability to keep the peace through negotiation and economic interdependence.

If these things happen, we should be able to continue in our current pattern and slowly, steadily, and with great respect and caring for the people in uniform, shrink our armed forces and liberate our economy from dependence on arms sales.

What kind of S&T policy do we need to create the world I would like my grandchildren to live in? The answer is simple: One that is not dramatically different from the one we have now, but one that has evolved in a humane direction. Unfortunately, we cannot take it for granted that it will evolve that way. We have choices to make, and if we make the wrong ones we could end up living in quite a different world.

A powerful and positive influence moving S&T policy in the directions I have described comes from the changing relationship between government and business (or, in the more traditional terms of political theory, between the state and the market). With the collapse of communism, humanity's faith in markets to provide what they need has become axiomatic. The state is shrinking, and will continue to do so. The public interest is coming to be implemented as a complex web of incentives that governments put in place to shape what businesses do. The action that achieves the public interest is largely in the private, not the public, sector. I expect these trends to continue.

Against this backdrop of shrinking government, the steady growth of public spending on the research enterprise is highly significant. Even as government hands off so many functions to the private sector, it maintains its commitment to new knowledge and education. We see this in sickness and in health, through Republicans and Democrats, and amidst a dramatically changing global scene. I think that we see in this development the outlines of a new type of state, with a new relationship to markets, and with a special and central link to science and engineering. I will conclude with a few words about this new state.

Markets and businesses are wonderful sources of innovation, energy, and change. Private enterprise makes the global economy grow and, in order to operate effectively on a global basis, takes on important societal learning functions. Global environmental standards, for example, are emerging both from intergovernmental negotiation under public pressure and from consortia of firms who want to stabilize their business environments. Markets tear down old businesses but replace them with new ones. They make things available to us, and we choose the ones we want to make our lives better.

What markets do not do is invest broadly in the human capacity to take advantage of what the changed world offers. Markets under-invest in new knowledge and in human potential. In the next 25 years and beyond, we will need governments not only to support discovery, but also to provide the education, health care, and services that build community life. I call this type of government "the humane state," and I see it as a key to creating the world I want my grandchildren to live in. The humane state creates a healthy environment for business through its fiscal policies and regulatory structures, but takes as its main function the provision of resources for education, knowledge, and community.

Science and engineering are centrally important for the humane state. That state needs experts who can keep the public interest in view and who can listen to diverse voices. It needs scientists and engineers from many backgrounds to help develop the skills of the new economy in many kinds of communities, with different habits and cultural patterns. (Those open-boundary universities I described above are particularly well suited to this task.) And it needs scientists and engineers to develop public technologies to be purchased on behalf of the community—for example, appropriate technologies in energy, transportation systems, and health.

In summary, my vision for the world in the next 25 years has two parts. First, it is a world of shared prosperity, with a better distribution of comfort. And second, it is an educated and empowered world, in which individuals and communities make effective choices about how they live. Science and engineering have crucial roles to play in both aspects, and science and technology policy can—and should—help these individuals and communities play those roles.

10 Linking Scientific Research to Societal Outcomes

Michael M. Crow

Despite great advances during this century, science and technology have failed to address some of the most critical existing and emerging needs of society. In the late 1990s, the U.S. economy reached its 20th century apogee, largely driven by science and technology; but we still find ourselves with widening income gaps and in general, poor distribution of the benefits of science. Great scientific discoveries have been made over the past 50 years, but they sometimes seem to bear limited correspondence to the priorities and needs of all U.S. citizens and an increasingly global community. So, how can we design a science policy that will contribute its utmost to a multitude of widely distributed, highly beneficial social outcomes?

Vannevar Bush's 1945 report, *Science—The Endless Frontier,* established a social contract between science and society in which research investments were expected to advance the war against disease, ensure national security, and create jobs. But since the end of the Cold War, funding for science and technology has usually been rationalized in terms of contributing to economic growth and curing cancer. The President's Council of Economic Advisors and other economists have pointed out the high rates of return on investments in research and development. This spring, Federal Reserve Chairman Alan Greenspan repeatedly cited an unexpected leap in technology as primarily responsible for the Nation's record-breaking economic performance.

Science is certainly a significant contributor to economic growth, but a linear model does not do justice to its full contributions or impacts,

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nor does it help policymakers link scientific research to societal outcomes. And suggestions for the restructuring of U.S. science policy seem stuck in a funding-centered, input-driven paradigm.

Two assumptions that we have outgrown (assumptions that are too simple for the complexity inherent in science policy) are that science is a force for human good, all the time; and that socially optimal outcomes will emerge from the amalgamation of the results of individual scientific projects. In *Wired* magazine, Bill Joy, co-founder and Chief Scientist of Sun Microsystems, discusses where we might be headed if we do not think through what kind of a force science can be (see chapter 3). He points out the potentially negative outcomes of future research and shows us that science is not inexorably good. We should acknowledge the fear of what science makes possible, but we should also realize that what is possible is not certain. After all, science is discovery. The applications of that discovery or the future paths it makes possible are options. These options allow flexibility, speed, and agility in economic and social development.

As we go forward, we need to do two things with our science policy design. First, we need to focus on outcomes rather than only on inputs. Outcomes should receive attention and resources proportionate to their importance. Second, we need to restructure research portfolios so they more equitably distribute benefits and mitigate the social costs of technological change.

Science policy as it currently stands lacks a social dimension. Science and technology are formidable powers, but to benefit our society fully, science policy needs to be tempered with humanism. Policymakers need to consider social equity in the context of the distribution of the benefits of science; social purpose in terms of what might be the structural outcome of our scientific investments; and social enterprises, like research universities, for their economic effects.

Science has been increasingly called upon to inform policy-making, but successful linkages between the two have been extremely difficult to forge. We devote very little intellectual energy toward improving our incomplete understanding of the science-policy interface and the institutions focusing on this interface. Our scientific and technical abilities far outstrip our decision making methods and ability to understand the relationship between science and its many outcomes.

We have a science policy now that is heavily focused on the conduct of science and the funding of science. But what are the outcomes of this science? Social outcomes of science include social equity changes, social structure evolution, and social enterprise development. We have had some increase in our ability lately to link these together, but we have not included these outcomes as measures, inputs, or mechanisms into our national science policy apparatus. In order to be responsive to the world we live in, and in order to design policy with hopes of giving direction or purpose to scientific discoveries and technological applications, we must consider the various, complex dimensions of this world. For example, the recent conclusion of the efforts to produce the first-draft map of the human genome will have profound effects on not only human health and medical care, but also food production and consumption, insurance, the structure of scientific research and institutions, marriage and social structure, and even, to some extent, human evolution. It is fair to say that most of these science-driven outcomes have not been as fully considered as the funding of the science itself.

An outcome-oriented policy would, in part, rely on the conduct of science to generate technology that could be transferred to the larger economy to create new industries. This would be an economic outcome of scientific research. These nascent industries would require, and thus facilitate, the creation of new skills. This education represents a social outcome of scientific research. With new industries and education come new social structures and new institutions, generated by and allowing the continuance of partnerships (between and among universities, government, and industry) and knowledge transfer, precipitating the ever-more-informed conduct of science. There is a derivative engine here that is working in the form of cycles. This is not to suggest, of course, that we can design a master plan to work all of these things out. Rather, it is to illustrate that science policy, as we go forward, should be embraced in its totality. We should think about the dynamics of the cycles involved in science policy because investments in science create new institutions, new structures, shifts in the economy, and changes in social structures, all of which come back and impinge on one other.

A visual interpretation of outcome-oriented policy would be the circular linkage of the conduct of science with economic, social, and scientific and technological outcomes. Scientific research and various societal outcomes would act as dynamic inputs and outputs for science policy. This is exciting stuff, and highly complex. The successful linkage of scientific research to societal outcomes depends on our understanding and ability to embrace this complexity.

11 Why I Am Optimistic About the Future

Neal Lane

This chapter discusses three areas. The first is the President's FY 2001 R&D budget request, which envisions another century of progress for science and technology. Second, I will discuss some concerns about developments that could impede progress, specifically the Department of Defense's (DoD) R&D funding trends and our continuing inability to diversify the science and technology work force. Finally, I will give a snapshot of why I am optimistic about the future, and what I think we all should do—government, industry, and academia—to get the most from science and technology in the 21st century.

The Administration's FY 2001 R&D Budget Request

President Clinton and Vice President Gore have proposed a record-setting science and technology budget to Congress for FY 2001. The centerpiece is a nearly $3 billion increase in the 21st Century Research Fund (roughly the "fundamental" half of federal R&D activities) to address three critical national concerns. First, it funds the creative efforts that maintain our leadership in science and technology. Second, it funds the stream of innovation that ensures continued prosperity in the 21st century. Finally, it begins to restore the balance between biomedical research and the rest of our R&D portfolio. This balance underlies our progress toward national goals such as promoting long-term economic growth that creates high-wage jobs; sustaining a healthy, educated citizenry; enhancing national security and global stability; and improving environmental quality.

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The FY 2001 budget request for R&D continues the important R&D trends established by the President and Vice President, and raises the bar a bit. This is the eighth consecutive year that the President and Vice President have proposed increased investments in civilian research and development, which is up 43 percent during this Administration. In the FY 2001 budget, the 21st Century Research Fund grows by seven percent. The President's budget boosts funding for basic research by $1.3 billion. Since 1993, funding for basic research is up 52 percent. R&D support to universities increases eight percent ($2.1 billion), contributing to a 50 percent increase since 1993. And, perhaps most importantly, this budget substantially improves the balance in our R&D portfolio in recognition of the interdependence of scientific disciplines.

It is especially significant that the President's R&D request increases university-based research that will (1) ensure a strong science and technology (S&T) work force in the 21st century, (2) help close the opportunity gap, and (3) provide economic opportunity for all Americans. It also ensures the U.S. position as the world leader in science and technology, at least for the immediate future.

The President's budget also provides a substantial increase for most of the R&D agencies, including an additional $1 billion (a six percent increase) at the National Institutes of Health (NIH) and an extra $675 million (a 17 percent increase) at the National Science Foundation (NSF). The President has also requested major funding increases for S&T programs at the Departments of Energy, Commerce, Agriculture, Transportation, Interior, and Education, the National Aeronautics and Space Administration, and the Environmental Protection Agency.

Within the balanced R&D portfolio we are also proposing some very important interagency initiatives. In the area of energy, there is a new focus on biofuels; on developing clean, efficient energy technologies for the burgeoning international markets; and on strong support for research to improve domestic housing and make cleaner cars. We have a targeted effort to understand solutions for environmental policy challenges such as hypoxia, harmful algal blooms, and biodiversity loss. We are moving our robust global-change research program into understanding carbon uptake and storage in terrestrial systems and to take stock of what a changing hydrological cycle might mean for the planet. We have continued our strong support for education research. And among our efforts to address 21st century threats, we have proposed a new Institute for Information Infrastructure Protection, which is a new partnership with industry.

I want to highlight just two interagency initiatives. First, the FY 2001 budget proposes a bold new initiative in nanotechnology research. This effort, known as the National Nanotechnology Initiative, will provide a $225 million increase in the emerging fields of nanoscience and nanoengineering. This increase nearly doubles the current federal investment. Roughly 70 percent of this new funding will go to university-based research. This investment will also help meet the growing demand for workers with nanoscale science and engineering skills. The Administration believes that nanotechnology will have a profound impact on our economy and society in the early 21st century, perhaps comparable to that of information technology or cellular, genetic, and molecular biology. It is likely to impact all these fields and many more.

The second interagency initiative the President highlighted in his S&T budget will build on our national investments in fundamental research in information technology (IT) with a $600 million increase. The basic goals driving our Information Technology for the Twenty-First Century initiative include:

- long-term information technology research that will lead to fundamental advances in computing and communications;

- investments in advanced computing for science, engineering, and national goals; and

- study of the economic and social implications of the information revolution and training the IT workforce, with a special emphasis on ensuring that all Americans can benefit from these technologies.

The President's S&T budget plots a bold course of strategic growth and prosperity through discovery. Many people, especially the President and the Vice President, worked very hard to present this $3 billion increase to Congress with the hope, even the expectation, that we could work with the membership on a bipartisan basis to see it successfully enacted.

That is why it is especially galling this year to find ourselves—yet again—confronted with congressional budget resolutions that threaten our ability to adequately fund the S&T investments needed to carry our nation into the 21st century. There are Members of Congress in both parties who are trying to help. Congressmen Rush Holt (D-NJ) and Vernon Ehlers (R-MI) and Senator Edward Kennedy (D-MA) have worked to add $1 billion for R&D to the Budget Resolutions. But the

Budget Committee Chairmen have established shortsighted spending priorities and budget ceilings that could translate into severe cuts for many vitally important programs.

If allowed to proceed unchecked, Congress could stall our progress toward national goals and balance in a healthy R&D portfolio precisely at the moment in history when we can best afford to invest in America's future. As of the time this is written, the Republicans' budget plans reduce the discretionary accounts by $17 billion below the President's request. Senator Pete Domenici (R-NM) and Rep. John Kasich (R-OH) indicated that they would spend more on defense (about $500 million higher than the President requested), and would equal or beat the President's request on education, veterans' medical care, and NIH. The result is that all the rest of nondefense discretionary spending must be cut deeply in order to meet the ceiling imposed by the Budget Committee Chairmen. Our estimates show this will need to be about ten percent. Clearly, as President Clinton recently stated, a budget that shortchanges critical national priorities, like R&D, is not the best path for our nation. The American people agree with the President on this.

We must not become complacent in the face of "sense of the House" or "sense of the Senate" resolutions to provide increases to Function 250 that do not meet the President's request. We should remember that our S&T budget is not just a balance sheet, it's a blueprint for our future. How regrettable then to see Congress falling back into its familiar, nasty partisanship proposing a flawed budget that is a blueprint for chaos. The congressional budget resolution, based on irresponsible tax cuts, would make sharp reductions in key S&T priorities and shortchange critical national investments. It targets valuable science programs that are vital in keeping the United States in the front ranks of research and innovation. Such a budget would be unrealistic, unwise, and unconscionable and would fail America's scientists and engineers by pretending they should do more with less.

There is a lot of work to be done if we want a good R&D budget at the end of this appropriations cycle. We all need to become deeply involved in this effort.

Concerns About the Future of S&T

We must make sure that science serves society. As the Vice President says, our newest technologies must help advance our oldest and most cherished values. After addressing this issue, I will return to the R&D budget and take a brief look at R&D investments by the Department of Defense (DoD) in particular. I will then suggest some goals for consideration.

Science and Societal Values

Now is the right time to talk about science and societal values because, by any measure, it is an extraordinary time of achievement and promise in science and engineering. There is a long and intriguing list of possibilities that are suddenly close to reality. Things that a decade ago were still considered science fiction are now happening. It can be a truly great "century of discovery." The accelerating pace of discovery generates a sense of even greater urgency to ensure that this accumulated knowledge is used to create opportunities for society and to make this next 100 years a great "century of opportunity" as well.

One way to do this is to better couple the laboratory to the factory through public-private cooperation. The Clinton-Gore Administration has worked very hard to establish public-private partnerships—such as the Partnership for a New Generation of Vehicles—that attempt to better connect the fruits of R&D with economic, health, and other social benefits. But we have also recognized the need to better understand the impact of rapid technological change on people's lives and on their attitudes. For this reason, the Administration has set aside funds to study the ethical, legal, and social implications of our science and technology endeavors. A recent article by one of society's most astute techno-pioneers, Bill Joy, a founder of Sun Microsystems, made us all stop and think. In his article titled "Why the Future Doesn't Need Us," (see chapter 3) he made us ponder the possibility that society could move beyond creating "virtual reality" to creating a form of "real virtuality," in which we humans are no longer necessary. His comments were viewed by some as suggesting that our own technological progress could turn on us.

However, I believe it is more likely he had Albert Einstein's admonition in mind: "Knowledge of what is does not open the door directly to what should be." Creating continuous new knowledge in science and technology without knowing where it will lead is a visionary path. But creating societal opportunities with our current science and technology is a humane and appropriate path. This is not a choice of one road or the other like that famous Robert Frost poem. We must pursue both and designate resources for both journeys.

Whenever I hear someone talk about two paths, I think of Yogi Berra's advice: "When you come to a fork in the road, take it." Truly, I believe that asking both what is possible and what is sensible is the only thing that can save us from some of the anti-technology fervor that has gripped Europe and is looming here on issues such as genetically modified organisms, cloning, and stem cell research. And this is only the beginning.

Another area where technology touches our lives—and our children's lives—is education. As we use science and technology to expand opportunities for the nation, just as significantly, we need to focus on how science and technology can be used to create opportunities for individual growth. For example, we are close to realizing our goal to equip every school in the nation with Internet access. It is, of course, important to ask how best to use this technology for learning. But unless the teachers and students have access, there is no way to find out. Through partnership with the private sector, we can empower every school child in the nation to learn information-age skills.

And we had better keep that goal front and center if we expect our country's future to outshine its past. The increasing economic role of science, technology, and engineering has, in turn, increased demand for all types of scientific, technical, and engineering workers, from technicians to Ph.D. research scientists and engineers. We have some serious issues to address in that regard.

The S&T Work Force

A recent report from the National Science and Technology Council called *Ensuring a Strong U.S. Scientific, Technical, and Engineering Workforce in the 21st Century* reaches two fundamental conclusions about our science, technology, and engineering work force. First, these workers are essential to both the private and public sectors. In the private sector, they help propel the economy and provide valuable services. In the public sector, they support important federal missions. Second, it is in the national interest to vigorously pursue the development of domestic science, technology, and engineering workers, both women and men, from all ethnic groups.

Science, technology, and engineering jobs present great opportunities for American workers. They are among the fastest growing in the U.S. work force. Unemployment in science and engineering occupations, with some variability among fields, is quite low. But if current trends persist, our nation may begin to fall far short of the talent needed to spur the innovation process that has given America such a strong economy and high quality of life. The ongoing debate over H-1B visas suggests that worker shortages are limiting our economic growth. America is indeed fortunate that talented men and women from all over the world have chosen to study and work in the United States. Our leadership in S&T is largely due to this situation. But we cannot expect it to continue. We will have to do a much better job of growing our own talent, which we should do for a number of reasons.

Demographic trends also raise concerns about the nation's ability to meet its future high-tech work force needs. Historically, non-Hispanic white males have made up a large fraction of U.S. scientists and engineers. But in the 21st century this fraction of the U.S. population is projected to decrease significantly. Other U.S. population groups, such as Hispanics and African Americans, form a much smaller part of the high-tech work force, but their populations as a fraction of the U.S. population are expected to increase markedly in the next 50 years. This implies that science, technology, and engineering workers may decline as a fraction of the total work force if the relative participation of these respective groups remains unchanged. If we want a strong high-tech work force, members of all groups, including non-Hispanic white males, must participate at increasing rates. High-tech careers will have to become more attractive to everyone in our society—women and men from all backgrounds and all parts of the country.

I am concerned we are not doing enough to increase participation through the actions of government, industry, and academia. And I am worried that it seems to be getting harder, not easier, to make progress, in part due to new legal and political pressures that reduce our options.

R&D Investments in DoD

Defense funding of R&D, particularly in the nation's universities, has been a key element of America's advancement to become the world leader in science and technology. But for some time now defense-sponsored research and development has failed to keep pace with foreseeable demands of the military services, and, as a result, the innovation base is eroding.

It can be argued that some of this drop results from the Defense Department's ability to reap the benefits of an advanced commercial technology base. It has historically done much to foster this. As a December 1999 report of the Defense Science Board Task Force on Globalization and Security points out, the commercial sector is now driving the development of much of the advanced technology that is being integrated into modern information-intensive military systems.[1] But, at the same time, we have been seeing a retrenchment in corporate basic research, with both industry and the military increasingly relying on government-sponsored, nondefense basic research to provide the intellectual groundwork of their industrial research and development efforts. Moreover, we will always have defense-unique requirements that commercial technologies will not be able to fill. A fear is that failure to renew our military research and development base may leave us unprepared for future conflicts.

Cuts in DoD-sponsored R&D also undermine our historical distribution of responsibilities for stewardship of the S&T enterprise. Although DoD's support for R&D in universities is a small portion of DoD's R&D budget, it plays a crucial role in many universities' research portfolios, and it shoulders a major share of the federal government's investment in certain key fields. For example, DoD provides more than half of all federal support for electrical engineering and mechanical engineering at universities; it funds nearly half of all federal support for computer sciences and materials engineering; and it plays a strong role in several other fields such as oceanography, mathematics, aeronautical engineering, and astronautical engineering. Cuts in DoD R&D are likely to have a disproportionate impact on these fields, and that will impede our efforts to restore balance in our national R&D portfolio.

Indeed downward pressures on all of our investments have begun to show their effects in our national S&T enterprise. Over the past several decades, R&D funding has declined as a percent of the federal budget. The federal R&D budget, civilian and defense, has stagnated as a percent of the gross domestic product (GDP). Compared to our strongest economic competitors, the United States government spends less, as a fraction of GDP, on civilian R&D. (Some may well ask whether a certain percentage of GDP is the right measure. Because it provides a snapshot of our level of effort for scientific discovery against a backdrop of our total economic effort, I believe it is.)

Optimism About the Future of S&T

These problems did not arise overnight. In fact, the Administration's actions over the past seven years have helped to sustain America's ability to create and capitalize on world-class science and technology. President Clinton and Vice President Gore funded increases in the federal research and development budget even as we steadily brought the budget into balance and, ultimately, to its record surpluses today. The R&D budget has actually grown as a percentage of total discretionary spending, which is a clear indication that the Administration considers investment in science and technology a high priority for the nation. Indeed, the Administration's strong FY 2001 budget request for S&T is unprecedented.

David Gergen's editorial in the April 10, 2000, *U.S. News & World Report* warns us that we will miss Bill Clinton, and comments that the President's imagination is on fire about today's scientific and technological revolutions. Gergen has it exactly right. And there is no reason we cannot continue on the trajectory set by the Clinton-Gore budget request. Congress has the opportunity to demonstrate strong bipartisan support for S&T, as one of the clearest high-return investments for America's future.

But if we are to place federal funding for R&D on a new, upward trajectory, we will need to have a solid rationale for doing so, and we will need to set some goals. The truth of the matter is, we in America have been eating our seed corn for a long time now, and it is time to grow some more.

The private sector understands this. The direct impact of new knowledge and technologies on the economy has never been clearer. As a consequence, industry support for R&D continues to grow far faster than federal R&D funding or the U.S. economy as a whole. But industry's R&D is focused on short-term needs. Just as we have started to reinvigorate our support of the physical sciences, mathematics, computer science, and engineering to restore balance to the federal R&D portfolio, we also need to reap the rewards of fiscal discipline and get the overall federal investment in science and technology balanced and up to a level that can support a robust future economy and provide all the other social benefits our people need. So here is what I hope government, industry, and academia will work toward over the next five to ten years.

Proposed Goals

I have two proposed goals for the U.S. government. First, set a new target for R&D as a percent of GDP. Bill Clinton and Al Gore proposed a national target (public and private) of three percent. We are practically there. It is now time to stretch ourselves a bit more, particularly with respect to federal funding. We ought to consider a target, perhaps not for total federal R&D—where defense development needs will strongly influence the number—but for the 21st Century Research Fund. The Research Fund includes NIH, NSF, DoD basic and applied research, and most of the other civilian R&D programs. It is currently funded at just under 0.5 percent of GDP. In ten years, we should double that to one percent. We can argue about exactly what the right percentage should be, but we have to have a goal.

Second, while our researchers will be making extraordinary discoveries in all fields of science and engineering, we need a national challenge to galvanize Americans' interest in science and technology and encourage more young people to pursue careers in discovery. There are a number of possibilities. For example, should we colonize the Moon or Mars? A recent issue of *TIME* focused on "Visions of Space and Science" and suggested that much of America is fascinated by the latter possibility.[2] Another challenge might be: Do we need a planetary early-warning defense system to alert us to incoming asteroids? One will reach us eventually.

Perhaps we can excite young minds with target dates for one or more of the following:

- developing an integrated prediction model for the world's regional climate and weather, or eventually controlling the weather;

- establishing space-based observations of planetary systems throughout the galaxy;

- proving a final theory of the subatomic world;

- building customized chemicals and smart materials using the newest technologies;

- providing gene-based, personalized medical care, including nanorobotic systems for prevention, diagnosis, and treatment; or

- designing a mind/brain computer interface. We could use the mind to figure out how the brain works, and eventually how the mind itself works.

Others will have other ideas, perhaps better ones, for challenges that can stimulate a whole generation of young women and men to learn math and science, to get excited about careers as scientists and engineers, and to want to be a part of a peaceful and sustainable technological future. We can foresee exhilarating opportunities in biomedicine, computing and communications, climate and weather, nanotechnology, elementary particles, and cosmology. (Oh, to be young again!)

I hope industry will set some goals as well. I have three in mind: First, double your share of university-based R&D funding by 2010. If you do, you will get breathtaking research discoveries and outstanding S&T workers. It will be a good investment.

Next, take the same pledge that 25 companies—from Adobe Systems to Xerox—took April 6, 2000, at the White House. Promise to spend at least $1 million dollars, annually, for the next ten years to expand diversity in the high-tech work force. These funds will be used for a wide range of programs, including scholarships, job training, math and science programs, internships, and other programs to encourage minorities, women, and persons with disabilities to pursue science, engineering, and technical careers. Long-term commitments by the corporate community will not only promote diversity in the work force but will also help address America's need for additional skilled scientists, engineers, and technical workers.

Third, I urge companies to partner with local school boards to provide year-round, high-wage employment for math and science teachers and help recruit them. The Office of Science and Technology Policy and the National Institute of Standards and Technology will soon launch a pilot program partnering local school boards and businesses to foster high quality K–12 education. School boards and local businesses will recruit and hire math, science, and technology teachers and provide them with yearlong salaries for at least four years. Business leaders will guarantee summer employment for the teachers and provide them with the opportunity to develop innovative teaching methods reflecting real-world experience of science and technology in the workplace. Close cooperation between schools and businesses is expected to lead to additional benefits such as businesses placing volunteers in the classrooms and providing summer employment or internships for advanced students.

Last, I want to propose some changes for academia to consider. Why not set a target for increasing the number of minorities and women who graduate with S&T degrees? I suggest ten percent per year through 2010. That may not be the right number, but it can start the debate. We have to set a realistic goal. But also we cannot afford to continue to make so little progress.

How about making math and science literacy a prerequisite for graduation with a baccalaureate degree? Rather than just talk about the lack of public understanding of science and technology, universities and colleges have it within their power to do something about it.

Finally, by the year 2010, ensure that all K–12 teachers have the necessary knowledge and are well prepared to teach their math and science classes. It is time for all parts of research universities and teachers' colleges as well as schools of education within universities to work together to make sure no more students are "bored" away or "scared" away from math and science. Until this happens—and is visible in your communities—it will be hard to convince supporters that the universities really care about K–12 education.

Conclusion

The S&T compact that we often talk about requires all the parties—government, academia, and industry—to extend themselves beyond the ordinary boundaries that govern our relationships. Last year, the Vice President called on the scientific community to look for new opportunities in the new millennium. He has called for the development of a "New Compact" between our scientific community and our government based on three tenets. First, as we continue to probe the most fundamental questions of nature (and let us never be distracted from this quest), we must also do more to ensure the best use of science and technology to sustain our prosperity, create jobs, and grow the economy for the 21st century.

Second, we must make sure that we not only generate the fruits of discovery, but also share the excitement and rewards of discovery. That means working to ensure that more people have access to technology and to rewarding careers in science and technology.

Finally, as I mentioned above, we must do more to make sure our newest technologies help advance our oldest and most cherished values. We have a weighty responsibility in this area, and, once again, I challenge all of us to become civic scientists and engineers, all deeply engaged in using the knowledge and tools of our profession to make a better world.

If science and technology hold the key to prosperity, health, and security in the 21st century, we must be bolder in the demands we make of ourselves and the expectations we hold for all stakeholders in the enterprise. Only by acting together, can we constitute a whole greater than the sum of our parts and achieve the full potential of this great nation.

Endnotes

1. Hicks, Donald A. *Report of the Defense Science Board Task Force on Globalization and Security.* Defense Science Board. Washington, DC. December 1999.
2. *TIME.* April 10, 2000. Vol. 155, No. 14, Visions 21.

12 The Age of Transitions

Newt Gingrich

I have spent the last year at the American Enterprise Institute and the Hoover Institution thinking about the direction we are going as a nation and what the implications are for the nature of the scientific endeavor in the next generation. I would like to share with you some of my observations.

I believe we are experiencing an explosion of knowledge of such scale that it is hard to describe. If you think of an S-curve of technological development (slow when discovered and then rapidly ascends before it slows down), I believe the S-curve we have been experiencing opened with computers and communications. Most people think we are in the middle of this change. We are probably about one-fifth of the way into it at most.

As we accelerate up the rest of the computer-communications S-curve, I believe we are simultaneously starting up a second S-curve of change. This curve is the triangle of nanoscience, biology, and information interacting in a way that creates capabilities that were unimaginable 45 or 50 years ago.

The nano world may be the most powerful new area of understanding in the triangle. "Nano" is the space between one atom and about 400 atoms. It is the space in which quantum behavior begins to replace the Newtonian physics. In this world of atoms and molecules, new tools and new techniques are enabling scientists to create entirely new approaches to manufacturing and to health. Nanotechnology "grows" materials by adding the right atoms and molecules. Although years away, nanotechnology may be at least as powerful as space or computing in its implications for new tools and new capabilities.

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The nano world also opens up our understanding of biology and biology teaches us about the nano world because virtually all biological activities are at a molecular level. Thus our growing capabilities in nano tools will expand dramatically our understanding of biology. Our growing knowledge about molecular biology will expand our understanding of the nano world.

Beyond the implications of the nano world for biology, in the next decade the Human Genome project will teach us more about humans than our total knowledge to this point. The development of new technologies will increase our understanding of the human brain in ways previously unimaginable. From Alzheimer's to Parkinson's to schizophrenia, there will be virtually no aspect of our understanding of the human brain and human nervous system which can not be transformed in the next two decades.

Steven E. Hyman, Director of the National Institute of Mental Health, made the point that the revolution in brain science was largely driven by physics and mathematics, not biological science. This revolution created opportunities to begin to understand how the brain works at levels unimaginable 15 years ago. As a result, we are beginning to realize that the human brain itself may be one of the most complex aspects of our intellectual universe. The mathematics that may ultimately be required to understand what is going on in the brain may be far denser than we ever thought. These are the kinds of things that may be telling us that we are on the edge of another new frontier.

Finally, the information revolution will give us vastly better capabilities to deal with the nano world and with biology. It will give us the technology and equipment to use this kind of knowledge and to create these kinds of breakthroughs in biology, material science, and quantum computing (as well as many areas that are only beginning to be plausible in the last ten years). As an historian, I believe that if we do get those kinds of breakthroughs, they could be larger in their impact than all of the developments of the 20th century.

It is the synergistic effect of these three systems intersecting (nano world, biology, information) intersecting with the computer/communications S-curve that will lead to an explosion of new knowledge and new capabilities. We will simultaneously be experiencing the computer/communications revolution and the nano world/biology/information revolution. The period of intersection of these two curves will be a constant age of transitions.

Every area of science is affected by the age of transitions. For example, in astronomy, the weekly and monthly breakthroughs in new knowledge are just a hint of the potential information new space-based and ground-based systems will unveil in the next decade. In quantum mechanics, the simple reality is that we can predict certain results fairly well but remain far from a full understanding of complex systems. In biology we have unlocked the alphabet of the human genome but are only beginning to approach the mysteries of protein folding. In microbiology we have identified about three to five percent of single-cell organisms in the most studied water (from waste treatment facilities) and well under one per cent of the single-cell organisms in the ocean. The list could go on.

An Opportunities-based Science Budget

Policymakers need to rethink the responsible level of commitment necessary to continue advancing at this rate. Even advocating (which I have done) for a doubling of all government scientific funding, not just the National Institutes of Health, is shortsighted. We need a bold assertion of *all* the opportunities that are made possible by modern instrumentation, computation and the Internet. We need an opportunities-based science budget.

My proposal is simple. The National Academy of Sciences, AAAS, a Congressional Commission, or an *ad hoc* group, should produce an opportunities-based budget rather than an incremental one. If the right number to save lives, to stop Alzheimer's disease, to cure diabetes, to have national security, to launch the economic growth of the next 50 years is 11 billion or 14 billion or 7 billion, so be it. We need an opportunity-driven number, not a politically or accidentally driven number. And we ought to have it across the board. One way or another, we should get the debate on an opportunities-based approach to science started.

The idea for an opportunities-based science budget was born out of a meeting initiated by John Porter (R-IL) when I was Speaker. When we in Congress decided to balance the budget, John came to me to suggest that we should bring in every senior research vice president of every pharmaceutical company in the country. About 35 people came to the meeting. Every one of them said that free enterprise only begins immediately after scientific discovery. If we do not make the investment in the initial discovery, our capacity to create growth industries, to lead the world in these products, and to save more lives could all disintegrate within a decade. They made a very compelling case. I think this meeting was a major step in the right direction. One of our weaknesses was getting other industries to understand that they have an equal obligation. Many of our industries indirectly depend on these breakthroughs and should also be actively making the economic case for this kind of budget.

For example, an opportunities-based budget would find out how much the Defense Advanced Research Projects Agency (DARPA) can use. In many ways DARPA is one of the unsung heroes of the Internet and the computer age. The fact is that there are times when peer-reviewed research is too incremental, too narrow, and too small to create large-systems architecture. Both the National Aeronautics and Space Administration (NASA) and DARPA did a great job by convincing us that we needed this next big breakthrough and we needed this large amount of money to do it. The country then invested in ways that probably would not have survived if the investment had not been done in these kinds of programs.

Another example of why an opportunities-based science budget is needed was illustrated on front page of the *Washington Post* last year. One story was about a sudden, unexpected snowstorm that hit Washington. Next to that story was one about the discovery of weather patterns in the Pacific Ocean that may change weather all the way from China to the Sahara. This involved an effect that we did not know existed three years ago. Before we spend trillions of dollars on a Kyoto policy decision, we should spend a billion or two on a ten-year project with systems architecture similar to the International Geophysical Year in 1957–58. This effort should be aimed at optimizing our understanding of the planet's climate. This is not an irrational decision. Investing a billion dollars first to decide whether or not it is right to spend a trillion is what every business leader would consider a sound economic decision. It is important to come from the larger world to the smaller world of science and say this is the amount we can now spend intelligently.

With an opportunities based science budget, we can identify the opportunities we have to dramatically decrease human pain and death and allow the financial savings to be reapplied to other research areas. For example, the scientists who work with juvenile diabetes say they believe within a decade we can either totally mitigate the impact or potentially eliminate the disease. They think there is practical reason to say this because the system's architecture of knowledge is there. What is the return on investment if diabetes is eliminated? This disease is the largest single cost factor in Medicare. Every seventh dollar of Medicare is spent treating the side effects of diabetes, which are blindness, heart disease, kidney disease, and loss of feet. We can, as a nation, justify a very high investment to get such a solution. Using arguments like this can be a much more aggressive way of asserting that these breakthroughs are real, this new knowledge is real, and this opportunity is real.

Areas of Funding Emphasis

I believe an opportunities-based science budget should emphasize the following five funding areas:

- There should be an increase in peer-reviewed money allocations to enable more high-quality proposals to get full funding. The scale of shortfall was highlighted when the Director of the National Science Foundation (NSF), Rita Colwell, stated that funding existing first-class research proposals would require more than twice as much funding as the $4.7 billion currently appropriated. Yet even her testimony understates the potential shortfall in science. Dr. Colwell is describing the current shortfall within the current system. The psychology of a budget-constrained science community minimizes proposals of appropriate large-scale research projects.

- We must begin to fund a new generation of large projects that could create great breakthroughs. The Defense Advanced Research Projects Agency invested millions of dollars without peer review, which made possible the creation of the Internet. In astronomy, the terabytes of data that will be produced daily ought to be captured in an open, Internet-based, archived, virtual observatory. The current plans will capture only a tiny percentage of the data. In weather and climatology, we are drifting toward spending trillions of dollars under the Kyoto Global Warming protocol. Yet we fail to increase the current budget by less than one-tenth of one percent as much for a worldwide climatology project. The National Oceanic and Atmospheric Administration is so strapped for money to keep its current systems operating that it legitimately shies away from this grandiose scale of investment in knowledge and research, which actually should be the minimum investment.

- Money needs to be available for highly innovative, "out of the box" science. Peer review is ultimately a culturally conservative and risk-avoidance model. Each institution's director should have a small amount of discretionary money, possibly three to five percent of their budget, to spend on outliers. The history of plate tectonics should remind all of us that accepted wisdom could be wrong.

- We need a new commitment to integrate the hobbies and funnel the interests of amateur scientists into real discovery. Significant recent findings by amateur scientists include animal tracks in New Mexico older than dinosaurs, and discovering supernovae in distant galaxies. It is important to remember that Darwin the amateur beetle collector nurtured Darwin the evolutionary theorist. There is plenty to be discovered and explored by amateurs, and the Internet combined with new instrumentation can harness and focus the work that amateurs already do.

Shawn Carlson recognized the untapped resource of amateur scientists and in 1994, founded the Society for Amateur Scientists. He and others guide amateur scientists in their research and enlist their help in gathering data for professional scientists. The society's Web site sends out calls for assistance on projects at universities and laboratories around the country. The potential is massive but the funds are lacking.

The Ames Research Center hosts a program that is another excellent example of amateurs, in this case students, helping professionals with research. National Aeronautic and Space Administration funds a collaborative project between Ames and the nonprofit Marine Sciences Institute, a science education organization that runs educational cruises for teachers and students in the San Francisco Bay area. The program's director, Lynn Rothschild, has utilized the samples and physical data (temperature, UV radiation, water clarity, etc.) collected by students on the cruise to help her identify UV-absorbing pigments in plankton and to measure DNA damage experienced by plankton in the Bay at different times of the year. This information could help scientists understand more about environmental effects on coastal communities. Students are being immersed in research by giving them part-ownership in scientific data. This program not only nurtures the next generation of scientists but also has allowed Ames to provide useful data that would otherwise have an economically prohibitive price tag. We need federal funding to support more programs like this one.

- We must have new approaches to learning that combine the discovery process, virtual reality, and a 24-hour/7-day-a-week Internet-based opportunity for the committed learner. In particular, we need an immersion approach to virtual learning about the quantum world, which is so counterintuitive to our daily experience of the classical Newtonian world.

This investment will also require a dramatic overhaul of science and math education. This is a national security issue of the first order. Barely half of our computer science graduate students working in the United States were born in the United States, in large part because our own high schools are not graduating enough students with the math and science capabilities to sustain American society in the 21st century. While we benefit from being an educational beacon for the world, it should alarm us that our own society is not producing enough math and science students for us to remain a world leader. We cannot assume that we can import people from India, China, Germany, and Japan to substitute for the collapse of the American capacity to educate its young. We should think through from the ground up about rebuilding science and math education. In my judgment learning science and math is harder than most other kinds of learning. There is a reason in a highly wealthy society that people at the margin do not go into these areas. Part of the reason has to do with the way we now teach these subjects, especially science. We teach science as facts to be memorized rather than science as a great adventure to be pursued. I suggest that we look at this issue in a very broad way.

I think we must be very bold, as bold as necessary. For example, I would pay high school students to learn calculus. Look at the National Defense Education Act of the 1950s. I would consider the notion that a major in math and science as an undergraduate you would pay no interest on student loans. If we do not do something that bold, do not give all the theoretical process and philosophical arguments, do not produce enough students who can do math and science, we are out of the game. We have had 15 years of dealing with these problems and, in my judgment, we have gotten nowhere. The relative improvement in science is trivial compared to the requirements of entry-level courses. The number of Americans who continue to invest their minds and their lives in science and math is clearly too small, with the result that our graduate schools cannot find enough qualified applicants.

This is a national security issue of the first order, and I do not believe we can survive as a major power if we do not solve it. I do not believe we can continue to buy the rest of the planet's children to do our science. At some point their quality of life in their homelands will be good enough that they won't stay in the United States. When that happens we will have a precipitous decay in the conduct of our science. The British problem of 1870, and the reason they could not compete in the end with Germany and America, was that they could not convince their elite that it had to learn to be technical and managerial in its functioning.

The Digital Opportunity

One step in the direction toward the overhaul of math and science education and the involvement of amateur scientists in the process of discovery would be to digitally connect the entire country. I believe that every four-year-old child ought to be given a personal computer funded by the government. As soon as they learn to read and write, they ought to get an Internet connection (with screening for pedophiles and pornography). Our public policy should stipulate that every family will have access to the Internet. The City of LaGrange, Georgia, is the first city to do this. They have announced that they are going to connect everybody through their cable system. Already 85 percent of the population is connected to cable. The city will cross-subsidize to get the other 15 percent connected. This is not complicated. If we decided to give every four-year-old child a computer, computer companies would figure out a way to make a remarkably inexpensive base computer because production runs would be so high.

The endless frontier of discovery needs both scientists and nonscientists to push its limits. The implications of the opportunity for young people to be real scientists at the discovery level on a worldwide basis are astonishing. We have the technology that can involve everyone in the excitement of scientific discovery. It may be worth our while to look at how to mass-produce the tools needed so that every science student could be involved in the discovery process. They could be on the Internet and could be connected locally to an institution such as a university or federal laboratory so they could learn real things in a real way. This is totally different from the current mind-numbing, fact-oriented, explanation of things that are 40 years out-of-date, which passes for much of today's science education in America.

This country achieved 98 or 99 percent penetration on the telephone because we insisted as a nation that is what we want. We invented the Rural Electrification Administration so everybody could have electricity. In light of this success, arguments about the feasibility of providing computers ought to be over. In 1800, universal public education was a radical idea; it did not start until 1844, in Massachusetts. In 1900, in the South, suggesting free textbooks was a radical idea. In 1928, Huey Long won the Governor's race in Louisiana by advocating free public textbooks. Today, we take both for granted.

There is not going to be a digital divide in this country. This country does not live with divides. They are wrong; they are not American. We have the resources, the intelligence, and the capability to unite this country with technology. It is cheaper than remedial education and it is cheaper than prison. It is doable.

Scientists As Citizens

Without active participation of scientists in the public policy process neither the opportunities-based science budget, nor significant progress on the five focus areas can be achieved. Scientists must act as citizens. It is ridiculous to say that because what they are doing is noble and interesting these should not also function actively as part of our society. Scientists have as much an obligation to attend their representative's town hall meetings, write letters to the editor, or come to Washington to visit their congressional representative as do dairy farmers, sugar planters, coal miners, or any other legitimate group who represent their own concerns. If scientists truly believe that they are on the cutting edge of the future, they have a double burden because not only do they have self-interest, they also have the moral obligation of educating our democracy into creating a better future. Yes, citizenship is frustrating, but it is a privilege we must exercise. Yes, it means occasionally scientists will be involved in controversy. Yes, they have to learn communication skills such as speaking in a language everyone else in the room can understand. But these are doable things. They also are vital not only to the survival of this country, but also to the future of the human race. The answer to poverty in the developing world is vastly greater productivity. The answer to health in the developing world is a dramatically better system of delivering health and preventive care. These all grow out of science.

Most of the great breakthroughs in the last 200 years have at their base an expanded scientific knowledge. Scientists have a moral obligation to be good citizens. I urge every scientist to at least once a year talk to your elected official. Do not complain about Washington not understanding scientific research if scientists in this country are not willing to take on the burden of talking to people in positions of authority. That is a simple challenge. I do not mean to sound so harsh, but I am fed up with brilliant people explaining that they are too busy to be part of our democracy.

Scientific Investment's Affect on National Security

At the end of the enormous zones of new opportunity, serious national security implications exist. I serve on a study committee that reports to the Secretary of Defense, a committee that President Clinton and I created when I was Speaker of the House. This committee is charged with looking out to the year 2025. I think we could easily not be the leading power in the world in 25 years. That could happen if we fail to adequately invest in research and development and do not massively overhaul math and science education in this country. If the world of knowledge is in fact on the edge of very substantial breakthroughs, we must make them or someone else will.

We could be launching another quarter of a century of American progress. Or we could be like Britain between 1870 and 1900, which failed to modernize and, as a result, it fell behind Germany and America for the first time in almost two hundred years. It is absolutely imperative that we understand the extraordinary national security implications of making (or not making) a full-scale investment in research and development.

Conclusion

I am a fiscal conservative and support a lean, effective government. But the economy of today is based on the science of the past two generations. The economy of tomorrow is going to be based on the science of today. Anyone who wants to maintain a healthy American economy in the future had better support a very substantial science investment in 2000 and 2001 or it will not be there. Responsible investing in scientific research is not only the right thing to do for America, but will vital for our society's health and survival.