D.ALLAN BROMLEY

Science, Scientists, and the Science Budget

To influence R&D funding, the science and engineering community must learn what determines priorities.

Several times over the past 3 1/2 years I have been asked, explicitly by Congress and implicitly by others, to rank the research and development projects supported by the federal government in order of importance. Although those making this request have usually been motivated by good intentions, I have consistently resisted. The science budgets with which I have been involved in the Bush administration emerge from a process far too complicated to be represented by any single linear ranking of R&D projects. The science budget is itself a statement full of priorities, but those priorities exist along a number of dimensions.

This multidimensionality reflects the many different objectives for R&D support in today's society. A partial list of these objectives would include meeting national needs (such as national security, health, industrial productivity, and environmental protection), expanding the frontiers of knowledge, educating students, maintaining the nation's store of scientific equipment and facilities, ensuring U.S. preeminence in science and technology as well as their effective use in our society, and meeting past commitments. Individual projects inevitably contribute to more than one objective. The largest and most ambitious projects usually contribute to them all.

The task of arriving at a science budget is further complicated by the complex relationships among these various objectives. For example, certain pairs of objectives are commonly seen as defining the extremes of continuous spectra: basic research versus technology development, small science versus big science, civilian versus defense research, research versus education, and so on. Often these pairs are taken to be opposite and antagonistic, but a closer examination usually reveals quite a different picture. For example, each year the administration must strike a balance between the work that individual investigators wish to do today and the equipment and facilities that those same investigators will need 5 to 10 years from now to define and reach the frontiers of their fields. When posed as little science versus big science, the two goals seem antithetical, but in fact they are complementary and synergistic.

D.Allan Bromley is the assistant to the president for science and technology and director of the Office of Science and Technology Policy.

Because of the synergism among R&D objectives, the challenge is often to achieve balance among goals so as to achieve them all most effectively. In practice, this entails making a cascade of priority decisions throughout the budgetary process. These priorities are conveyed to the Congress in the president's annual budget submission, and the Congress then applies its own priorities to the president's proposals in arriving at final appropriations. From the outside, the system may appear to be chaotic, but more often than not it results in decisions that are remarkably sound.

From the earliest days of his campaign George Bush emphasized the importance of investing in science and technology, and he has maintained that emphasis throughout his first term. At the most immediate level, funding for research and development has increased substantially. If Congress enacts the President's FY 1993 requests for R&D, support for civilian R&D will have gone from $21.3 billion in FY 1989 to $30.4 billion, an increase of 43 percent. Basic research funding will have gone from $10.6 billion to $14.3 billion, an increase of 35 percent. Even defense R&D has gone up in current dollars, though the total defense budget has fallen.

President Bush has also sought to involve the scientific and engineering communities much more extensively in the federal government's R&D decisionmaking. He established the President's Council of Advisors on Science and Technology (PCAST) so that he and his top aides could receive input on science and technology directly from distinguished representatives of the private sector. He elevated my position within the White House hierarchy and nominated four associate directors for the first time in the history of the Office of Science and Technology Policy (OSTP). He has also given considerable support to the strengthening of the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET), which provides another avenue for private-sector input into federal decisions.

Most recently, after much discussion between the White House and the Congress, the Critical Technologies Institute has been established. It will be administered as a Federally Funded R&D Center by the Rand Corporation under contract with the National Science Foundation. It will be directed by an operating committee consisting of the cabinet secretaries of the R&D-intensive agencies and five senior members of the Executive Office of the President (EOP). The President has asked me to chair this committee.

The Institute will have a number of functions. It will make possible longer-range strategic planning for technology and its application than is possible in the normal short-response environment of the Executive Office. It will provide support for the ever-increasing number of legislatively mandated studies that are being requested of OSTP and other EOP offices. And it will make possible the much simpler and easier utilization of private-sector expertise in validating and calibrating the activity of governmental bodies.

Despite this increased present and projected access to federal policymaking, many scientists and engineers remain frustrated with science and technology policy at the federal level. I have spoken with more than a few who dismiss the process as narrowly political, as responsive largely to special interests. That has not been my experience. Policymakers need to balance a large number of objectives in arriving at sound policies, only some of which are based purely on scientific and technological criteria. If they are not successful in balancing these objectives, they risk damaging the science and technology enterprise.

I want to lay out some of the objectives that policymakers are trying to achieve in arriving at an R&D budget and to note some of the many points at which the scientific and engineering communities need to contribute to federal decisions. It is absolutely vital that the communities provide this input, even if it cannot be the only influence on a decision. Without this input, policymakers must nevertheless act, but they will be lacking essential guidance.

Bottom-up or top-down

One of the major reasons for the success of U.S. science and technology is the fact that its programs are built largely from the bottom up. In most other countries, a science and technology budget is established at a high level of government and is then divided among different programs. Here, the situation is much more pluralistic. The desires of individual scientists and engineers are reflected in proposals developed by individuals and groups of individuals with shared research goals. These proposals are then filtered by the agencies as they put together their R&D portfolios.

One of the best aspects of this system is that if one agency does not like a particular idea, the chances are

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good that another agency will find it appropriate to its mission. More than 20 federal agencies, in addition to private industry and other nongovernmental entities, support U.S. research and development. As a result, good ideas have a high probability of being supported somewhere within the system.

In such a pluralistic system, however, coordination and strategic planning can be difficult. As a result, the Bush administration has greatly increased the role of FCCSET, which is the cabinet-level interagency body within EOP charged with coordinating federal activities in science and technology that cut across the missions of more than one agency. A particularly important activity under FCCSET has been the "crosscut." In a crosscut, an interagency committee begins by developing an inventory of everything that the federal government is doing in a particular high-impact area of science and technology. Drawing on that information, the committee then establishes strategic objectives and priorities for a coordinated federal effort. Existing programs may be restructured or even eliminated to reflect new objectives, and new programs may be started to fill gaps or take advantage of opportunities. The result is an integrated government-wide effort rather than a heterogeneous collection of purely agency programs.

The President's FY 1993 budget included special Presidential Initiatives based on these FCCSET crosscuts in five areas: high-performance computing and communications, global change research, mathematics and science education, advanced materials and processing, and biotechnology research. For the FY 1994 budget, FCCSET has recommended the addition of advanced manufacturing as a new crosscut.

The FCCSET process would seem to embody elements of top-down planning, but in fact it draws its strength from the bottom-up contributions of the individual agencies. Suggestions for crosscuts and other FCCSET activities arise from the agencies and are reviewed and approved by the full FCCSET. If an agency chooses not to cooperate in the process, FCCSET cannot and does not attempt to force it to do so. In this way, the administration has sought to bring the diversity of U.S. science and technology to bear on focused problems of national importance. It has been extremely encouraging to me to see the unprecedented level of cooperation engendered by FCCSET as well as what I might term the peer pressure for quality generated when different agencies compare and integrate their respective programs.

By law all the members of FCCSET and its committees must be federal employees, but the FCCSET committees have been very careful to structure the crosscuts in such a way as to catalyze interactions with the private sector. A large number of organizations have helped shape FCCSET initiatives, and the final programs reflect the needs of the private as well as the public sector. For example, the Computer Systems Policy Project, a cooperative effort among computer companies, did a wide-ranging study of the High-Performance Computing and Communications program last year, and many of its recommendations have been incorporated into the HPCC program plans.

PCAST has also reviewed all of the FCCSET initiatives and has provided valuable input to the members of FCCSET committees. In addition, PCAST has formed ad hoc panels in many of the areas being covered by the FCCSET crosscuts to maximize the availability of private-sector input into these activities.

Small science and big science

Another point of emphasis in the Bush administration's R&D budgets has been funding for individual investigators, who continue to constitute the heart and backbone of U.S. science. The budgets of the past two years have each proposed increases of about 10 percent for individual investigator research, and the Congress has responded favorably to these requests. As a result, the federal government now funds more individual investigators, and at a higher total level of support, than it ever has.

However, funding for individual investigators makes up only about 10 percent of the total federal

R&D budget. The remainder goes toward support of a tremendously diverse set of other activities, from user facilities at national laboratories to weapons development projects in industry, from agricultural experiment stations to large science and technology projects serving broad groups of researchers.

These large projects, often referred to as megaprojects, are especially visible, but there are many difficulties inherent in using them to draw any sharp distinctions between big science and small science. Megaprojects include single facilities (the Superconducting Super Collider) as well as coordinated programs of research being done largely by individual investigators and their students and associates (the Human Genome Project). Some large projects (such as telescopes or some accelerators) pursue purely disciplinary research, whereas others (for example, the U.S. Global Change Research Program) are focused on more thematic research.

Some of what are often grouped with the megaprojects in public discussions, including such projects as Space Station Freedom and the Space Exploration Initiative, have never been primarily science projects, although for convenience they are included with R&D in the budget. But they are justified primarily on the basis of considerations such as exploring physical frontiers, increasing appreciation of science and technology, maintaining national leadership in a given area, or taking the initial steps in a great human adventure and only secondarily on their long-term (though quite certain) contributions to scientific and technological progress. To criticize them on the grounds that they do not advance science sufficiently is to fail to recognize their multiple objectives.

Megaprojects that do have substantial basic research components are essential to the future of individual investigator research. They should therefore be seen not as competitors but as enabling projects that serve the current and future needs of broadly based science. They, too, are investments in the future. If the growth of a megaproject were to squeeze out support for individual investigators, that project would be defeating its own purpose. It is the responsibility of each administration—and of the Congress—to ensure that the balance between megaprojects and individual investigator research is maintained.

But although the administration and Congress implement this balance, it is the individual disciplines that must decide what the balance should be. Only those at the forefront of a field can decide on the proper mix of large projects, individual investigator research, and other organizational arrangements, within given funding projections, that can best advance knowledge in an optimal fashion. Individual disciplines have a responsibility to set these priorities and to convey that information to decisionmakers in a timely and useful way, recognizing, however, that there will necessarily be other inputs to the ultimate decision.

Academic research

The United States places greater demands on its research-intensive universities than does any other nation. We expect them to do much of this country's fundamental research as well as to train the young people who will use the resulting new knowledge in effective, creative ways. The success of our research-intensive universities in meeting these expectations has been a critical component of this nation's science and technology preeminence.

Reflecting this success, funding from all sources for R&D at colleges and universities has gone from $4 billion to $17 billion in the past 15 years, a doubling in real terms. Nevertheless, the academic research community is experiencing very real and understandable frustration, despite these funding increases. A number of factors have contributed to this distress. There are a larger number of researchers, and many are submitting multiple proposals and amended proposals, severely stressing the peer review system. The costs of doing increasingly sophisticated research have gone up faster than inflation. New regulations have brought increased administrative costs, which have effectively reduced funds available for the support of research itself.

Most important, academic research has, to some extent, become the victim of its own success. Progress in research has generated an unprecedented number of opportunities, and our success at training academic researchers has produced many young people who are more than ready to grasp and explore these opportunities. Though available levels of funding have increased, the numbers of such opportunities and researchers have increased even faster.

Our national goal of excellence in science and technology requires that our research universities con-

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tinue to constitute the heart of our national R&D efforts. Federal agencies and U.S. businesses would be severely limited in trying to achieve their objectives without the participation of faculty and students within our world-class institutions of higher education.

Even as we focus national attention on the sorry state of precollege education in this country, we cannot take our leadership in higher education for granted. We have to ensure that our system of higher education—long the best in the world—remains healthy. To that end, PCAST and FCCSET have begun major and complementary reviews of the health of our research-intensive colleges and universities and of the appropriate nature of the relationship between the research-intensive universities and the federal government in a rapidly changing environment. PCAST has held a number of public meetings around the country to gather input from researchers, administrators, and the members of the public for its study, and the FCCSET committee is gathering data for its analyses. The results of these studies, which will be available in late 1992, should do much to point the way toward a more vigorous and productive partnership between academia and government.

Basic research and technology development

Yet another axis along which the administration works to achieve balance is that between basic research driven by individual curiosity and more applied R&D focused on relatively specific goals. The federal government's rationale for investing in basic research has long been clear: Because no one can predict where, when, or to whom the benefits of that research will flow, no single organization or institution can justify adequate levels of investment.

The Bush administration believes that the same is entirely true with respect to the development of certain generic, precompetitive technologies—technologies that have not yet reached the point where an individual company could decide whether or not a specific one of them can be profitable to it. In these cases, too, no one can predict, *a priori,* where, when, or to whom the benefits of that technology will flow, so society will inevitably underinvest in those technologies without governmental involvement. In OSTP's 1990 report *U.S. Technology Policy,* we spelled out some of the assumptions and other aspects of this policy.

Clearly, however, this administration does not consider it appropriate to provide federal support for very limited technologies that benefit a specific industry at a specific time. That is what we would expect to result from what we would define as an industrial policy—one that attempts to pick winners and losers in the marketplace. Nevertheless, we do believe that the federal government has a very important role to play in the spectrum that begins with basic research —where the federal government has in most cases already played a strong role—through to the point where it is possible to assess the commercial applications of a generic technology.

A useful test as to whether a technology is precompetitive is whether a company is willing to spend money on it in a cooperative joint venture with its competitors. The results from precompetitive technology research can be shared by a group of companies without reducing the incentives for any of them to further develop competitive proprietary products based on the results of that cooperation.

One way in which the government can support the development of these generic technologies is directly through the federal budget, but many other forms of leverage are also available. In some cases, the government needs only to act as a catalyst for the formation of partnerships or consortia among companies, universities, and federal laboratories. A very large number of these partnerships have been established, and more are being created at an accelerating pace. For example, the Department of Defense (DOD) has helped support Sematech, a consortium of companies working to leapfrog an entire generation of semiconductor manufacturing processes so that the United States can regain its traditional preeminence and market share in this area. Consortia are working on batteries for electric automobiles, on high-temperature superconductivity, on new composites for automobiles, on plant biotechnology, and in many other areas.

We are also working very aggressively to benefit from the enormous investments we have already made over the years in our more than 700 federal laboratories and to make the laboratories more responsive to national needs. An important step here is to have the peer review panels of experts from government, the private sector, and academia, which now evaluate the quality of completed research, participate much earlier in the R&D process—in the selection and design of projects. In this way, the private sector would be much more involved in the development of the laboratories' research programs and would be more prepared to participate actively in the work and make greater use of the results.

Civilian and defense R&D

The ratio between civilian and defense R&D is an often-cited measure of an administration's intentions toward science and technology, but in fact the two numbers measure quite different things. Over 90 percent of defense R&D is aimed largely at the development, testing, and evaluation of new and improved weapons and support systems. The vast majority of defense R&D is therefore judged by criteria quite different from those applied to civilian R&D.

Nevertheless, there are important commonalities between defense and civilian R&D. Defense R&D has always had major commercial benefits in addition to its primary goals, and those benefits remain strong today. But in contrast to the past, when frontier technologies developed in the defense sector diffused in large numbers into the civilian sector, today the trend is in the opposite direction: Advances in defense capabilities have increasingly benefited from technological innovation in the civilian sector. As a result, many key government R&D programs, such as the National Aerospace Plane, find joint sponsorship in the Pentagon and in nondefense agencies.

Because of this convergence, we must increase the two-way linkages between defense and civilian R&D and draw upon commercial endeavors for defense purposes as we support technology transfer from government laboratories to the private sector. The FCCSET process offers some insight into how this convergence is occurring. The Department of Defense is involved in all five of the FCCSET crosscuts, often as a leader of individual initiatives. DOD's involvement grew out of a need to more effectively fulfill its mission, yet this involvement has other major implications throughout the defense and civilian sectors.

As Operation Desert Storm reminded us, America's tremendous scientific and technological strength provides the qualitative edge that has long helped preserve peace. Despite the end of the Cold War, continued uncertainties require that a robust science and technology program be maintained as the foundation for future defense capability. Above all, support for defense R&D must be maintained as total defense spending is reduced if we are to protect ourselves against technological surprise.

National versus international

The national and international components of R&D form another axis along which governments try to achieve a balance. Of course, science has always been one of the most international of human activities. But today knowledge has truly become a global commodity; it rapidly flows around the world to those who can use it most effectively.

Because of the increasing economic importance of this knowledge, some have called for tighter controls on the international flow of scientific and technological information—for example, through the restriction of foreign acquisitions or limitations on the outflow of U.S. technologies. But I believe that most such restrictions would ultimately be counterproductive. Rather, what we need to do is become much better negotiators, in the private as well as the public sector, when striking international agreements involving science and technology. When the United States provides increased access to some aspect of its science and technology, we should see to it that we get comparable benefits in return. The development and use of technology can and should be a positive sum game in which all parties can benefit.

There is one component of science and technology where international cooperation is essential—namely, megaprojects that have become too expensive for any one nation to afford. If such projects are to proceed, they must draw on the shared contributions of many countries.

In the case of international megaprojects, however, the differences among governmental institutions and their procedures can sometimes cause difficulties. In particular, the U.S. approach to these megaprojects tends to differ from that of other nations. In most other

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countries, when a project is approved, all of the required funding is appropriated at the outset. When the U.S. Congress, during its annual budget cycle, questions a project that was already approved, our collaborators sometimes find it difficult to understand why we are reconsidering something that they thought was already decided and final.

Because of such episodes, and because in a few cases we have been less than sensitive to the needs of our collaborators for timely communication about changes in projects, the United States has gained a reputation as something of an unreliable partner in international cooperation. This has led us to discuss alternative approaches to international cooperation in the case of megaprojects. One element in such an approach would be the initiation of international discussions well before a specific project ever got started. The question at issue, instrumental characteristics, location, funding, schedule, and involvement of various countries in an ensemble of megaprojects could be discussed in advance, so that collaboration can be made more effective from the very beginning.

Basically, what we need to do in each particular area of science and technology is to come together as an international community and ask ourselves: What are the next questions that need answering to push forward our common frontiers? We could then develop expert advice as to what we need in the way of facilities and instrumentation, where we are going to put them, how we will fund them, and how we can take advantage of the best possible international expertise available.

The subject of megaprojects in science was the leading agenda item at a meeting of the science ministers from all of the Organization for Economic Cooperation and Development (OECD) nations held in early 1992. At that meeting, the science ministers agreed to establish a forum that would facilitate such exchange of information about potential megaprojects at an early conceptual stage. The participants at the forum would be the senior scientists, senior instrumentation specialists, and senior political officials who could speak authoritatively on the science, the instrumentation, and the policy and planning involved in the projects. The first meeting of the forum was held in July 1992 to determine the priorities, methodologies, and arrangements for the forum's future work.

The role of scientists

In all of the cases discussed above, the ultimate balance between complementary objectives can only be struck through the political process—by weighing the needs of different groups and working toward consensus. But in each and every case, input from the scientific and engineering communities is essential. If this input is not forthcoming, decisions will still be made, but they will be made on the basis of incomplete and inadequate information.

In some cases, technical criteria should be the most influential basis for government action. This is particularly the case for merit review of competing projects, but it also applies more broadly. In recent years, a number of disciplines such as astronomy/astrophysics and high-energy physics have undertaken priority-setting exercises to arrive at a broadly agreed-upon list of activities and projects that should be pursued. Although these disciplines have not gotten everything that they requested, they have been much more successful in shaping governmental decisions than have those disciplines that have not set priorities.

At the same time, it bears emphasis that priorities depend critically on their environment, which can change rapidly and dramatically. But if the criteria upon which the original priorities were developed are rational and consistent ones, then they are entirely adequate to the development of priorities appropriate to new situations. As a result, the criteria have much greater longevity and stability than do priorities, and we need to focus just as much attention and effort on the evolution of national criteria for the establishment of priorities in science and technology as on the priorities themselves.

Scientists and engineers influence government decisionmaking in a number of other ways. They participate in professional societies and associations that seek to influence policy. They serve on advisory committees and panels that interact directly with federal officials. And they are political constituents with an expertise that commands the respect of policymakers. As such, when they avoid special pleading, they can influence decisions in areas that are not directly related to R&D, as they have in arms control.

The desired roles require a high degree of what I might term scientific statesmanship. By tradition, scientists and engineers have been much better at representing their own interests than they have been at placing those interests within a broader context. But today, science and technology face new kinds of pressures. As the discretionary part of the federal budget has become more and more a zero-sum game, science and technology are viewed as being in direct competition with many programs that have very vocal and powerful constituencies. As such, the investments represented by science and technology are increasingly susceptible to being squeezed out by what are presented as more pressing needs.

In this context, nothing is more counterproductive than for various parts of the scientific and engineering community to cannibalize one another in public or in the budget process. The assumption behind this behavior tends to be that if funding does not go to your project, then it will go to mine. But Washington simply does not work that way. If it chooses to cut support for R&D, Congress is much more likely to spend the funds on immediate consumption than on other investments in the future. For better or worse, all forms of R&D are viewed in much the same light by policymakers, and they will tend to rise and fall together.

The public debate over Space Station Freedom provides an excellent example. Although the station is not primarily a science project, space activities have helped to build support for other forms of investment in the future. If Congress were to cancel the station, it is highly unlikely that those funds would flow to other parts of the R&D budget. Indeed, when the Congress threatened to cut funding for the Space Station in 1991 and the Superconducting Super Collider in 1992, it was clear that very little of the liberated funding would have gone to support of R&D. That is why I believe that scientists and engineers must come together to promote *all* research and development, and not just particular areas, to the public and its elected representatives.

It is true that scientists and engineers who become involved in policymaking run the risk of being perceived as just another special-interest group. But science and technology differ from many of the concerns pressed upon the federal government in that their benefits to society far outweigh the benefits to any specific group. Nevertheless, the risk of appearing excessively self-interested argues for a very broad-based approach to public outreach, in which informing and influencing policymakers is just one of many objectives. After all, in a congressional hearing, an industrialist's mention of how important trained researchers are to a company can have more impact than the entreaties of 10 scientists.

According to the National Science Foundation, there are more than 5 million scientists and engineers in the United States—three times the number of U.S. lawyers and physicians combined. But effective advocacy by scientists and engineers requires a fundamental shift in attitudes. Scientists and engineers can no longer ignore the political process and trust that someone in Washington will eventually realize how important their work is to the future of the nation. There are too many groups with what may well appear to be more immediate needs than those represented by the long-term investments required for science and technology. Scientists and engineers need to recognize the terms of the debate, the criteria applied in decisions, and the perceptions of policymakers and the general public.

Both the administration and Congress have been extremely foresighted in funding science and technology, and many members of Congress agree with the administration that this nation is seriously underinvesting in research and development. But the executive branch and Congress are under intense pressure from a large number of groups, and in the tight budget climate of the next few years they will necessarily make particularly difficult decisions. Scientists and engineers must make their voices heard if the promise of U.S. science and technology is to continue to be realized.