The Federal View of Materials Science

1991 MRS Fall Meeting Plenary Address

D. Allan Bromley

It was over 200 years ago that Benjamin Franklin wrote, "The greatest inventions are those inquiries that intend to increase the power of man over matter." That comment has never been more true than it is today. The work of those of you here this evening in materials science and technology, in my opinion, is ushering us into a totally new age of materials, where our ability to control the structure and properties of matter is inevitably going to produce benefits not only to the citizens of this nation but to all peoples worldwide. It's an exciting time. It's exciting enough to be on the sidelines, as I am, and I'm sure it must be much more exciting to be actually involved in this tremendous adventure and in an activity that has the most profound consequences for all of us, our children, and our grandchildren.

Today I think it's fair to say that materials science has become as fundamental to technology development as mathematics is to the development of the natural sciences. Materials science and engineering has a tremendous impact on an enormous range of scientific activities, from almost every branch of applied technology through medicine through some of the most fundamental aspects of physics, cosmology, and other basic sciences. All the recent reports, and there have been many, on critical, generic, or emerging technologies—every one of them—has identified materials science and engineering as one of our most important activities in terms of its potential impact on and contributions to society. It is of particular pleasure for me to be here to discuss such a dynamic area of modern science.

I could, of course, run through enormous numbers of examples of areas that have recently turned out to be of great importance. But let me touch on only a few. Recent research that I have seen within the past six months has shown what I believe to be the ultimate in electronic devices: switches that operate through the action of a single atom, and transistors that activate through the motion of a single electron. High-temperature superconductivity and buckminsterfullerenes, both totally unanticipated just a few years ago, have the potential of producing dramatic changes in energy, transportation, and chemical technologies; in fact, their scope is limited only by our imaginations. Ceramic substitutions in aircraft engines will lead to extended lifetimes, weight reductions, and lower replacement costs. Again, we've only begun to get some appreciation for the changes that lie ahead.

D. Allan Bromley, Assistant to the President for Science and Technology and Director of the Office of Science and Technology Policy in the Executive Office of the President, is a noted nuclear physicist who has carried out pioneering studies on both the structure and dynamics of nuclei. He is on leave from his former position as Henry Ford II Professor of Physics at Yale University, where he was founder and director of the A.W. Wright Nuclear Structure Laboratory.

Since beginning his present appointment, Bromley has worked to strengthen the link between the scientific community and government policy, partly by revitalizing FCCSET (the Federal Coordinating Council for Science, Engineering, and Technology) and PCAST (the President's Council of Advisers on Science and Technology). He has coordinated planning in areas of science that cut across disciplines and funding agencies, such as global climate change, high-performance computing, math and science education, and materials science.

As plenary speaker at the Materials Research Society's 1991 Fall Meeting held in Boston last December, Bromley described the federal government's current role in policy making, goal setting, funding, and collaborative research and development in materials science. He also considered future needs in materials science, setting them in the context of broader U.S. science and technology goals. The following is an edited version of his address.

In the area of surface properties, diamond films have shown themselves capable of remarkable phenomena in a wide variety of applications, from machine tools to electronics. Ion-beam techniques are being used to produce corrosion- and wear-resistant surfaces as well as catalytically active surfaces. It gives me particular pleasure to mention a specific example in which Bill Appleton played a central and seminal role, and that is the use of nitrogen beams to nitride the surface of prosthetics for hip replacements. Those of you who have been involved with this know that in the past, because of corrosion-induced inflammation, the lifetimes of one of these prosthetics was 5 to 10 years at the most. So despite your need for one of them, you didn't get them until you were about 70 years old, the assumption being that they would then last as long as you would. Or you had to look forward to a rather messy replacement when the previous prosthetic became harmful.

As a result of the work that Bill and his colleagues did, they were able to show that nitriding the surface of these prosthetics reduced the corrosion rates by factors of between 400 and 1,000. This single effect has had the most dramatic consequences. It means that literally hundreds of thousands of people worldwide have now been able to have hip and knee replacements when they needed them, at whatever age, without having to worry about this replacement problem or corrosion-induced inflammation. This is the kind of development that becomes possible when materials scientists are not only excellent scientists but are sensitive to the societal applications of their work.

Of course, some people would say that these are rather exotic techniques, but much more mundane activities in the materials science field are also of enormous importance to us. The cost to the United States each year from damage resulting from metal corrosion or other types of failure in service amounts to hundreds of billions of dollars. Or take an even rougher example: Concrete of greatly improved durability that we now know how to make could result in roads with a lifetime of 50 to 60 years rather than the present 10 to 20 years. The cost of energy wastage in transformer cores, something we tend not to think about, amounts in the United States to nearly a billion dollars a year. Many of these inefficiencies and losses can be very substantially reduced through the kind of work that those of you in the room tonight have under way.

One of the most important areas of all is that of the high-temperature behavior of materials. Almost every industrial process in the United States and in the world is ultimately limited in its efficiency by the behavior of materials at high temperatures. A recent calculation that I have seen shows that for every degree Fahrenheit that one can raise the average temperature of industrial processing in the United States, the payback is two billion dollars per year. This gives a concrete measure of the enormous importance of the work that many of you are doing.

As Bill said earlier, I have been convinced for a long time that materials science and materials engineering have remained something of orphans at the federal level. This reflects the fact that they don't fit comfortably into the mission of any particular agency, and in fact they don't fit comfortably into the boundaries of the standard academic departments. Rather, materials science and engineering play a role in just about every federal agency that has anything whatever to do with research and development. Partly as a result of this fragmented nature of your field, it has not received the attention it deserves here in the United States.

One of the important breakpoints in your field was the publication, something over a year ago, of the Chaudhari/Flemings report from the National Research Council entitled *Materials Science and Engineering for the 1990s—Maintaining Competitiveness in the Age of Materials.* That report identified one of the major gaps in U.S. science, that having to do with synthesis and processing. It's important to recognize that we still enjoy, in this country, international leadership in developing new ceramics, new composites, new materials of all kinds, and we still retain international leadership in terms of characterizing new materials—we can tell you quickly how it will wear, how strong it is, and how it will behave under hostile conditions. But in a disheartening number of cases, in order to get a decent sample of the material that we have just invented so that we can characterize it, we find ourselves going elsewhere, frequently to Japan. The Japanese have what we would call super technicians—people of high reputation, prestige, and reward who have learned to do a few things, but to do them superbly well. We in this country have a lesson to learn from this. We have an enormous shortage, not only of technicians, but of super technicians. One of the things that the Committee on Education and Human Resources under my office has identified is that we tend to label technicians as either having fallen or having been kicked off the academic ladder prematurely. We have to change the reward structure and prestige that we accord such people. Otherwise we have no chance of remaining competitive in an increasingly technological world.

I need hardly emphasize that the processing of materials is at the very center of modern economies. It's essential to use high-quality, reliable products in an efficient and cost-effective manner. One of the tremendous success stories I think familiar to many of you in the room is that of the production of fiber optics. The development of a modified chemical vapor deposition technique enabled cheap and reproducible production of the optic cables that now increasingly tie all of our society together. Today, large-scale, high-temperature superconductor technology is evolving, but it's still awaiting the key enabling technologies that will allow us to produce, in quantity and reproducibly, large quantities of flexible, durable wires and ribbon.

Greater capabilities in processing and manufacturing offer enormous opportunities here in the United States. Yet we have not moved as rapidly as we should have to grasp these opportunities. One reason is that for a number of decades we in the United States have been in the grip of what I consider a very pernicious myth: that we have moved in a somewhat graceful fashion from an agricultural to a manufacturing to a service economy, dispensing with the outmoded sectors as we moved on to the next. Nothing could be farther from the truth and more destructive. In fact, each of the major sectors of our economies draws its strength from other sectors. Without a strong manufacturing sector, our service economy would wither very rapidly. By the same token, agriculture remains a very key part of our economy, with important implications for materials science. Much of the input to both manufactured goods and agricultural goods takes the form of services, from accounting and banking to sales and advertising. If we were to lose significant fractions of either our manufacturing or agricultural sectors, then we would very rapidly lose these components of the service economy as well.

The danger of the myth is not in that it describes reality, at least not yet. Manufacturing still accounts for more than one-fifth of our gross national product, and the percentage today is actually above the postwar average. But the myth skews the perceptions of our citizens and students and threatens to become a self-fulfilling prophecy. Already it is my firm conviction that it has led our country in ways that are not in our self-interest. Very few of our students are interested in production or manufacturing. Although the situation has improved in recent years, a few years ago less than 4% of the graduating class at MIT indicated any interest whatsoever in either of those areas. Yet these are the activities in which many of the other high-paying jobs in our society are based. If you haven't yet read it, I would certainly recommend to you the book *Manufacturing Matters.* Indeed it does. It is my intention that next year one of the areas that will receive a full interagency analysis in the federal government will be that of manufacturing.

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Fortunately, many of the opportunities in materials science and in manufacturing are now being addressed, and some very important progress has been made. I'm happy to say that one of the very major contributors to that progress is your own Materials Research Society, one of the fastest growing professional societies in the United States. By emphasizing interdisciplinary work, goal-oriented research, and materials of technological importance, you have contributed in a very major way to the maturation of this entire field.

I have already mentioned the NRC report, a major achievement in itself. As Bill mentioned earlier, at my request the NRC arranged for four regional meetings to be held to obtain public input and to obtain the best possible advice that we could use in implementing the recommendations of the NRC report. This resulted, as all of you know, in a document entitled—*A National Agenda in Materials Science and Engineering: Implementing the MS&E Report,* which was published by the Materials Research Society. That report emphasized the need for a strategic goal-oriented approach to planning materials R&D, with increased cooperation from industry, government, and academia.

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There has been a lot of talk about cooperation and partnership in various fields of science, frequently more talk than action. It is clear that you are an exception to this general rule, and I have been very much impressed by the level of cooperation that has already been achieved, largely through the efforts of your society in bringing together the related industries, the federal government, and academia. In doing this, you have also established yourselves as a model for the activity of professional societies in the future. In the past, professional societies have tended to focus primarily on their technical activities. But increasingly, in a world where we play zero sum games in budgeting at the federal level and where there is increasing competition for every federal dollar, it will become absolutely essential for professional societies to become more active in telling the Congress about the opportunities in their fields. That is the way it should be done. You should focus on the opportunities that are out there, opportunities that result from successes in the past that you were not able to follow up because of lack of support. This is an approach that the Congress can and will respond to much more effectively than it will to any approach that has even a hint of entitlement attached to it. Your society has been extremely successful in this respect and again has constituted a model for other societies.

The federal government has begun to respond to this message in a significant way. In the budget that the President sent to the Congress last January, you may recall that there was an $84 million special initiative on materials in the National Science Foundation's budget, with an emphasis on synthesis and processing. In its first year, this initiative covered three directorates within NSF and focused on electronic and photonic materials and on biomaterials. The intent is to begin to strengthen our competitive position in the United States in these important areas.

As Bill mentioned in his introduction, we have just completed—and I have recently forwarded to Richard Darman, director of the Office of Management and Budget (OMB)—the results of a full crosscutting analysis of materials science and engineering activities throughout the federal government. The body under which this analysis was performed—FCCSET, the Federal Coordinating Council for Science, Engineering, and Technology—was created back in 1976 specifically to coordinate activities across all the federal agencies. Materials science is a textbook example of why FCCSET was created. We need a forum where we can discuss programs in different agencies—in this case, in more than a dozen agencies—so that we can integrate them and bring them forward to OMB and to the President not as a collection of more than a dozen heterogeneous agency programs that all have a general common direction, but rather a carefully thought-out, integrated, and coherent national program in a particular area.

Over this past year the Subcommittee on Materials under one of FCCSET's seven standing committees, the Committee on Industry and Technology, has carried out for the first time in history a total inventory of what the federal government is actually doing in materials science. Prior to this, we had very little idea what we were doing in this important area. Some of the results of the analysis have been very interesting. We found, for example, that in the fiscal year just concluded the federal government spent $1.8 billion on materials research and development through 11 agencies. This does not include a rather large amount of materials science research that is included under the various classified programs in the federal government, classified programs particularly in the Departments of Defense and Energy. If these were added, the total materials science investment by the federal government would be very substantially in excess of $2 billion.

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Nevertheless, if we adjust for inflation, our investment in materials science today is almost precisely at the same level that it was 15 years ago. As a share of the total federal research and development effort for all of science and technology, that devoted to materials science decreased from 3.6% in fiscal year 1976 to 2.5% in fiscal year 1991. It is on the basis of this crosscut that we can remedy what I think is a very unfortunate trend. The crosscut has also shown us that the funding levels for materials vary widely across different subfields and materials classes. Research and development on advanced metals, for example, receives 18% of the total, followed by composites at 10%, superconducting materials at 10%, and magnetic materials, the lowest fraction at 1.5%.

Using the results of this analysis, the Subcommittee on Materials is currently recommending to my office and to the OMB—and through us to the President—ways to prioritize activities in materials science to avoid duplication of effort. Our goal is a national strategy for materials science, a strategy that will bring together the federal government, the private sector, and groups like this one—with particular emphasis on this one—so that we in the United States can do the best job that we possibly can with the resources that the Congress can make available to us in this area.

As Bill mentioned, we've been doing this sort of thing for several years in global climate change, in high-performance computing and communications, and in mathematics and science education. This year we've added materials science and biotechnology. Next year, as I indicated, I look forward to adding manufacturing. Each year thus far, each of the areas that has been subjected to a crosscut analysis has been selected by the President as a Presidential initiative in his next budget. I have no reason to believe that the President will not continue that practice with materials science for fiscal year 1993.

We should not expect, however, that there will be any radical shifts in direction or any enormous infusion of funds given the very tight federal budget. But what I think we can guarantee is a positive change in the support of materials science and technology, particularly in the applied part of materials research. It's going to make for a much stronger materials science and technology effort.

One of the very important features of this effort is the involvement of the private sector. They've got to be involved in the goal-setting and in all of the activities that determine our national program. In that respect, at the highest level of policymaking in our government is the President's Council of Advisers on Science and Technology (PCAST). This group of 12 very distinguished individuals from the private sector meets monthly with the President. It is the one occasion in the federal system where the President gets advice directly without any filtering by any bureaucracy. The longer you've been in Washington, the more astonishing that becomes—and the more important.

Specifically in the area of materials, John McTague, the vice president of Ford Motor Company, is chairing a PCAST panel that is charged with examining materials science and bringing to us in government the private sector view of federal activities. Working with them on this is Ralph Gomory, who until recently was chief scientist of IBM and is now president of the Sloan Foundation.

We've also been working hard to cement some of these relationships between industry, the national laboratories, and the federal government, and here we're using cooperative research and development agreements, the so-called CRADAs. We now have a very large number of them; I think something over 200 are now in place and transferring technology to the ultimate users. I don't specifically use the words "technology transfer" because I think those two words are among the most dangerous in the English language. They suggest that you can identify something as a "technology" at point A, wrap it up neatly, and transport it to point B, where you unwrap it and have it work. That, as all of you in the room know, is total nonsense. The only way that technology transfers is within the minds of humans, so what we have to do much more than we have is to arrange for much greater mobility of our scientific personnel through government, academia, and industry.

Another area where I think we have been making significant progress is consortia. Many of you know about the Automotive Composites Consortium formed by General Motors, Ford, and Chrysler in 1988 with federal input from what used to be called, and what I still call, the National Bureau of Standards, but is now the National Institute of Standards and Technology (NIST). In 1990, a formal arrangement with NIST was organized, and it was decided to pick the front end of a Ford Escort as the target of a cooperative study. In this arrangement no funds changed hands. The auto companies provided information, data, and materials to NIST, which in turn has provided very elaborate computer simulations of the flow patterns and pressure performance during the molding of these large composite parts that could replace large metal castings in the average automobile. The end result is a demonstration front end that is now undergoing crashworthiness testing. This can have a remarkable impact on the automotive industry and would never have occurred without the combination of the automobile company data and the supercomputer facilities available at NIST.

Another example is the Advanced Battery Consortium, which involves the automobile companies, the federal government, a number of smaller battery manufacturers, and the Electric Power Research Institute. This group is trying to find that factor of two in energy density that is all that separates us from a viably economic electric automobile.

I could cite many more examples, but this gives you an indication that we in this Bush administration believe that the government has a very real role to play in developing generic technologies, in moving from the basic discoveries through to the point where individual companies and industries can judge the applicability of the technology to their problems and activities. Materials science makes a particularly good testbed for this kind of collaborative activity. It's a field in which dramatic change is under way, and it is an appropriate time for us to develop, in addition to the changes in our science, changes in the institutions that allow us to apply that science. I have been enormously impressed by the effectiveness of your community's response to the challenges that are out there.

I began by quoting Benjamin Franklin, so let me conclude by quoting him once again. He wrote, "I have sometimes almost wished it had been my destiny to be born two or three centuries hence. For invention and improvement are prolific and beget more of their kind....Many of great importance, and now unthought of, will before that period be produced; and then I might not only enjoy their advantage but have my curiosity gratified in knowing what they are to be."

> Materials science is a textbook example of why FCCSET was created.

The world has indeed changed dramatically over the 200 years since Franklin made these comments. In large measure these changes reflect what has happened in science and engineering. But the one thing we can predict with complete certainty is the changes that lie in the decades ahead are going to be much more dramatic than those that we have seen thus far. Materials science and materials engineering, I am convinced, will play an ever-increasing part in bringing about those changes.

Audience Questions and Bromley's Answers

Question: You talked about the dangers of moving from a manufacturing economy into a service economy. One of the dilemmas that faces many U.S. manufacturing corporations today is that the rate of return in the service sector usually exceeds the rate of return in manufacturing, and so the pressure from the shareholders is inevitably to move in the direction of services. How can this very difficult problem be addressed?

Bromley: You've hit on a very serious problem—the very short time horizon that we have in our entire economy. There is no easy answer. The Bush administration has proposed a whole series of economic measures to try to increase the supply of patient, lower cost capital. One of the things that I find to be particularly attractive is a rather highly graded capital gains tax that makes it less profitable to churn securities on Wall Street—to pick up the profits from a particular dividend—as opposed to investing in a company and sticking with it to actually build our productive capacity in the country. There's no easy or quick answer. But quite frankly, part of it is educational, because unless we change this very short time horizon, our chances of remaining competitive in an increasingly hostile world are not very good.

Question: Could you comment on the federal science policy and funding, the zero sum game, and the SSC?

Bromley: A zinger at the end. First of all, let me comment on the question of science and technology support. Last year the administration requested a 13% increase in the support of science and technology, to a total of $75.6 billion from the federal government. Under the Omnibus Budget Reconciliation Act, that 13% increase for science and technology meant that we had to find other programs within the discretionary budget that we were prepared to cut back or to terminate. The same holds true this year. Obviously it's getting harder each year, but I am optimistic that when you see the budget at the end of January, you will find that we again have been able to find those programs to sacrifice to make it possible for us to increase funding for science and technology. The reason we can do that is because the President and Congress believe deeply that we, in the United States, are underinvesting seriously in science and technology. There is a reservoir of very real support that we can use if we make reasonable proposals and behave reasonably.

I am optimistic that we can continue the trend of the last several years in which we have had the largest increases for science and technology in recent history and where science and technology have been treated better than any other area in the federal budget. But this requires help from those of you in the room tonight because many of the programs we will try to terminate or reduce have vastly more effective constituencies than you constitute. We scientists are lousy constituents when it comes to making the political case for what we're trying to do and should be doing. I emphasize that a letter from a constituent to a Congressman or to a Senator—a thoughtful letter that doesn't ask for something personal—has a tremendous impact. If only a tiny fraction of those of you in the room tonight felt moved to write to your Congressmen and Senators and tell them what you think about the importance of science and technology, it could have a profound effect.

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Let me finish with the SSC. The SSC is the biggest scientific instrument that has ever been conceived. It can, and I'm sure will, answer some of the most fundamental problems that we can pose about our universe. Where is the fatal flaw—and there is a fatal flaw—in the Standard Model? And where did mass come from? There is a whole series of these questions. But as you all know, the SSC is a very expensive instrument. When it was approved by President Reagan and reapproved by President Bush and by the Congress, it was approved with two provisos. The first proviso was that one-third of the total cost come from nonfederal sources. The second was that it not move forward if moving forward meant cutting into the science and technology base. Those provisos still remain in force, and they admittedly are going to make it difficult. But the President is strongly supportive of the SSC, as is the Congress, and I am confident that it will move forward and that we will get the necessary foreign support. Nevertheless, I will be extraordinarily vigilant to be sure that the proviso that it not move forward at the expense of the rest of the science and technology enterprise be remembered.

Question: If we speak of manufacturing again and take areas in which we have a lead, like the aerospace industry, does your advice to the President extend into the areas of foreign investment in these companies or even take-overs?

Bromley: There is, as you probably know, in the Treasury Department an entity known as CFIUS, the Committee on Foreign Investment in the United States. I've arranged recently for my office to be a formal member of that group. The CFIUS office was set up by the Exon-Florio legislation, but the problem with the original legislation was that each purchase was considered in isolation. The question was, "Does the purchase of this specific company really impact the security of the United States?" and in something like 396 of the 400 cases thus far studied, the answer was "Well, I guess not," and so approval was granted. What is more important and what I think will happen is that we must begin to examine whether in fact a given purchase is part of a packet of purchases and whether there is a systematic effort to remove the technological underpinning from various sectors of our industrial economy. The review mechanisms are there, and we simply have to use them a little more aggressively than we have in the past.

Having said that, I want to go beyond and point out something about technology and international activities. There is always the worry—and people write and call frequently, saying "What are you doing to protect our technology from being taken abroad?" The answer is that I'm not doing anything to prevent *most* of our technology from being taken abroad because I remain firmly convinced that we gain much more than we lose by being very open with both our science and our technology. There are, however, certain things, mostly having to do with systems development in technology, that are very important to our national security, and those we should protect much more aggressively than we've protected anything in the past.

Most of you know about the CoCom regulations that govern what technologies could be exported. We had ridiculous situations where we had on the CoCom list 386-based computer technology when anyone could back a truck up to a Radio Shack in Frankfurt and then drive east to Vladivostock dumping units off along the way. That's the kind of nonsense that gets us nowhere. We have reduced the CoCom list by more than 80%. What remains on the list we will protect much more aggressively than we have in the past. What we will not protect we will make openly available, and we will all gain from it.

It is also important for us to recognize that one of our problems is that we have often sent out amateurs to do our technological negotiating. I can say that because I was one of the amateurs in many of these activities. We have not been adequately sensitive to what we could get and what we should get in our negotiations with other countries. That is something we are changing. We are becoming much more aggressive negotiators so that when technology flows from the United States to other countries, we want to be sure there is a reciprocal benefit coming back to the United States. You would be amazed at the number of cases where it is rather easy to identify what that reciprocal benefit should be.

Question: Would you tell us about the Critical Technologies Institute and what the present plans are for it?

Bromley: The Critical Technologies Institute was established about a year ago. Senator Bingaman's Armed Services Committee was the body of the Congress that wrote the legislation. The legislation as originally written had a number of structural difficulties, so this year, working with the Senator, we have a new structure. The funding will be handled through the National Science Foundation and will flow through the founding of a new Federally Funded Research and Development Center (FFRDC). The reason we're doing it through the NSF is because the NSF has all the machinery needed to make that happen rather quickly and OSTP is, by design, not a funding agency. There will be an Oversight Board that I will chair. It will have as members about six of the Cabinet members and four other senior governmental members yet to be appointed by the President. The NSF has just sent out the request for proposals to form the actual FFRDC that will form the Critical Technologies Institute or provide a home for it, and we anticipate that the Oversight Board will be in place within the next few weeks. I have every intention of getting it off to a running start; there is important work to be done. □

See the MRS Bulletin's interview with Bromley elsewhere in this issue.