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OA/ID Number:	08080
Folder ID Number:	08080-020

Folder Title:
Correspondence: Office of Science and Technology Policy [Climate Change, Global Change, various reports and booklets]

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G	13	25	5	2

THE WHITE HOUSE

WASHINGTON

June 25, 1992

Dear Michael:

Recently, the President submitted a pre-print version of the attached report on Science and Technology to the Congress. The report is required by law and was prepared by my office, with wide cooperation and coordination throughout the Administration.

The President's Report on Science and Technology serves as a summary of the accomplishments of the Bush Administration and offers an outlook for future progress in a number of key areas. As you look over this report, I am sure you will agree with me that this Administration has a great story to tell in terms of its activities in--and support of--science and technology.

Let me thank you for your strong and vigorous support in this effort. Your help, cooperation, and advocacy have made the President's science and technology record an historic success.

Sincerely,

Allan

D. Allan Bromley
The Assistant to the President
for Science and Technology

Attachment

Michael J. Boskin
Chairman
Council of Economic Advisers
314 EOB
Washington, D.C. 20500

N. Boskin

Excellent memo / Allan - Thanks - C.Y.

THE WHITE HOUSE

WASHINGTON

June 2, 1992

MEMORANDUM FOR CLAYTON YEUTTER

FROM: D. ALLAN BROMLEY Allan

SUBJECT: Cline report on Potential Damages from Climate Change

While I was on travel I received your note asking for comment on a summary of a report by William Cline of the Institute for International Economics (IIE) on the potential damages of climate change, and a letter to you from C. Fred Bergsten, Director of IIE, suggesting a briefing on the report.

This note is to provide you with some very preliminary comments; we have not yet seen the published report (I understand it is still in publication). We have seen an outline of the report, and a member of my staff attended Cline's seminar presentation at Resources for the Future (RFF) last month.

Cline's analysis

The best point in Cline's argument is that the calculation of the potential total damages associated with potential global warming cannot stop arbitrarily at an assumed doubling (from pre-industrial levels) of carbon dioxide (CO2) concentrations in the atmosphere. This is because, as Cline rightly points out, any damages would be associated with the total warming, which could theoretically proceed beyond the level of the climate sensitivity to a CO2 doubling (i.e., 1.5-4.5 degrees centigrade) if concentrations rise beyond a doubling. It is plausibie, if current emissions trends continue, that global concentrations will rise above a doubling of preindustrial CO2 by sometime around the year 2100.

On this basis, Cline criticizes the damage calculations performed by Nordhaus and others for stopping at a doubling of CO2 levels. Nordhaus estimated damages to the U.S. economy of 0.26% of GNP lost by 2050 as a result of the 1.5-4.5 degree C warming assumed to occur as a result of doubling CO2. Cline takes the analysis further, projecting a tripling or higher levels of CO2, and an associated warming of 10-18 degrees C, by "late in the 23rd century." He then estimates damages of 6% of GNP by that time, up to 20% of GNP under a more "pessimistic" scenario.

Questions about Cline's predictions

Cline's analysis is interesting from a conceptual point of view. But his specific damages estimates are subject to criticism or question on several fronts. First, several of the specific sub-categories are based on unusual assumptions. For example, Cline noted at the RFF seminar that his estimate of "species loss" was derived by taking the economic losses due to timber losses and salmon run depletions in the Pacific Northwest and "multiplying them by 25." No rationale for this surprising method was articulated. (Perhaps it will be explained in the final report.)

As a result of what seem to be strained assumptions like these, Cline's higher damage estimates are not solely the product of his extending the analysis over a longer time period and higher CO_2 concentrations and temperature changes than did Nordhaus. Even stopping at the CO_2-doubling assumed by Nordhaus, Cline estimates the damages at about 1% of GNP foregone from a 2.5 degree C warming (four times higher than estimated by Nordhaus).

Second, Cline's extrapolation over three centuries, while fascinating, generates quite tenuous numerical estimates. Cline appears to assume little or no progress in knowledge and technology that could assist adaptation over these centuries. Over the course of hundreds of years, know-how and technology would be likely to change significantly in ways that make societies and economies (and probably ecosystems) much more resilient to warming than they would be with current knowledge. Imagine anyone trying to predict in 1700 what the effects of future climate would be on world agriculture through 2000! Even assuming that this mythical forecaster knew with perfect accuracy what the global temperature record would look like over 1700-2000, he could not possibly foresee the dramatic improvements in agricultural output per acre that have occurred in the past three hundred years. Forecasting damages through 2200 today is similarly likely to overestimate future damages. Hence Cline's damage forecasts may not be as "stunning" as Bergsten's letter remarks.

It is worth noting that when Cline estimates the cost of limiting greenhouse gas emissions, he appears to be quite optimistic about the development of new technologies that will lower the costs of doing so. How then can he not be at least equally optimistic about the development of new technologies and knowledge to lower the costs of adapting to a new climate? One answer might be that rapid short-run warming would be too fast to adapt to, but Cline's projection is far longer-term than that.

Third, because the damages are expected to occur over several centuries, far-off losses would need to be discounted to calculate their present value. But Cline chooses a very low, almost negligible discount rate.

<u>Comparing predicted damages with the costs of preventing warming: no recommendation for stiff targets</u>

Finally, even assuming such high damages and low discount rates, Cline concludes that the cost of limiting emissions to prevent these damages (i.e, to prevent the increase in CO_2 concentrations that would generate the higher longer-term temperature changes on which his damages estimates rely) would be about equal to the damages prevented. Thus, even on Cline's analysis, limiting GHG emissions today is only barely cost-beneficial. This is a sobering finding.

Cline therefore ends up advocating not a top-down international target and timetable approach, but rather what he calls an "ambulatory targets approach" that begins with research, reducing energy subsidies, and voluntary national action plans. Only if the research reveals greater urgency would Cline advocate stiffer measures.

This is precisely consistent with U.S. policy and with the Framework Convention on Climate Change we have just negotiated. The point about reducing energy subsidies is one recently made by the World Bank, which estimates in its 1992 World Development Report that eliminating world energy subsidies of $230 billion a year (especially high in Eastern Europe and the CIS) would reduce global CO2 emissions by 10% by 2000, at a net economic gain for those countries. This may be a point the U.S. government could make more forcefully in the future.

These comments are, again, preliminary, as the final report has not yet been published.

THE WHITE HOUSE

WASHINGTON

February 18, 1992

MEMORANDUM FOR THE SECRETARY OF THE TREASURY*
THE SECRETARY OF DEFENSE
THE SECRETARY DESIGNATE OF COMMERCE
THE SECRETARY OF HEALTH AND HUMAN SERVICES
THE SECRETARY OF ENERGY
THE DIRECTOR OF THE OFFICE OF MANAGEMENT AND BUDGET*
THE CHAIRMAN OF THE COUNCIL OF ECONOMIC ADVISERS*
THE ASSISTANT TO THE PRESIDENT FOR NATIONAL SECURITY AFFAIRS*
THE ADMINISTRATOR OF THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
THE DIRECTOR OF THE NATIONAL SCIENCE FOUNDATION

FROM: D. ALLAN BROMLEY Allan

SUBJECT: THE CRITICAL TECHNOLOGIES INSTITUTE

The Operating Committee of the Critical Technologies Institute (CTI) was established by Public Law 102-190 on December 5, 1991. Seven of its members were specified by the legislation and four additional members were appointed by the President on January 10; these are indicated by asterisks in the above listing.

The Institute itself is being established as a Federally Funded Research and Development Center (FFRDC) by the National Science Foundation. The deadline for proposals from organizations and institutions wishing to house the CTI was January 31, 1992 and these proposals are now under review using standard NSF procedures and a selection panel toward whose membership many of you were requested, by NSF, to make nominations.

I enclose herewith a copy of the founding legislation for your convenience. The President has requested that I serve as chairman of the CTI Operating Committee.

You will note that the Operating Committee members specified in the legislation may designate persons to represent them on the Operating Committee. While I fully understand that your other duties may make this necessary on a continuing basis I would ask that, if at all possible, you agree to participate in the first few meetings that will establish the all important general policies and directions of the Institute.

In order for me to schedule an initial meeting of the CTI Operating Committee I shall much appreciate learning from you whether you are prepared to participate as a member of this Committee, at least for its initial meetings, or whether you wish to designate an alternate to represent your agency or department.

The legislation calls for not less than four meetings per year and you have my assurance that we will not meet more frequently unless we have matters of real significance to consider.

Because I am convinced that, properly managed, the CTI has the potential of providing effective support for the President's programs directed toward more effective utilization of technology in almost every sector of our society, I look forward to hearing from you and to working with you to make the CTI a success.

Enclosure

"SEC. 822. CRITICAL TECHNOLOGIES INSTITUTE

"(a) ESTABLISHMENT.—There shall be established a federally funded research and development center to be known as the 'Critical Technologies Institute' (hereinafter in this section referred to as the 'Institute').

"(b) INCORPORATION.—As determined by the chairman of the committee referred to in subsection (c), the Institute shall be—

"(1) administered as a separate entity by an organization currently managing another federally funded research and development center; or

"(2) incorporated as a nonprofit membership corporation.

"(c) OPERATING COMMITTEE.—(1) The Institute shall have an Operating Committee composed of 11 members as follows:

"(A) The Director of the Office of Science and Technology Policy.

"(B) The Secretary of Defense, or the Secretary's designee.

"(C) The Secretary of Energy, or the Secretary's designee.

"(D) The Secretary of Health and Human Services, or the Secretary's designee.

"(E) The Secretary of Commerce, or the Secretary's designee.

"(F) The Administrator of the National Aeronautics and Space Administration, or the Administrator's designee.

"(G) The Director of the National Science Foundation, or the Director's designee.

"(H) Four other members appointed by the President from among officials of the Executive branch (other than those referred to in subparagraphs (A) thorough (G)).

"(2) The President shall designate a chairman of the committee from among the members of the committee who are senior officials of the Executive Office of the President.

"(3)(A) The term of service of members of the committee appointed under paragraph (1)(H) shall be four years, except that of the four members first appointed, one shall be appointed for a term of one year, one shall be appointed for a term of two years, one shall be appointed for a term of three years, and one shall be appointed for a term of four years. The terms of appointment of members appointed under this subparagraph shall be designated by the President at the time of the appointments.

"(B) A vacancy in a membership of the committee referred to in subparagraph (A) shall be filled in the same manner as the original appointment. A member appointed under this subparagraph shall serve the remainder of the unexpired term of the predecessor of the member.

"(C) Members of the committee referred to in subparagraph (A) may be reappointed.

"(4) The committee shall meet not less than four times a year.

"(d) DUTIES.—The duties of the Institute shall include the following:

"(1) The assembly of timely and authoritative information regarding significant developments and trends in technology research and development in the United States and abroad, with particular emphasis on information relating to the technologies identified in the most recent biennial report submitted to Congress by the President pursuant to section 603(d) of the National Science and Technology Policy, Organization, and Priorities Act of 1976 (42 U.S.C. 6683(d)).

"(2) Analysis and interpretation of the information referred to in paragraph (1) to determine whether such developments and trends are likely to affect United States technology policies.

"(3) Initiation of studies and analyses (including systems analyses and technology assessments) of alternatives available for ensuring long-term leadership by the United States in the development and application of the technologies referred to in paragraph (1), including appropriate roles for the Federal Government, State governments, private industry, and institutions of higher education in the development and application of such technologies.

"(4) Provision, upon the request of the Director of the Office of Science and Technology Policy, of technical support and assistance—

"(A) to the committees and panels of the President's Council of Advisers on Science and Technology that provide advice to the Executive branch on technology policy; and

"(B) to the committees and panels of the Federal Coordinating Council for Science, Engineering, and Technology that are responsible for planning and coordinating activities of the Federal Government to advance the development of critical technologies and sustain and strengthen the technology base of the United States.

"(e) CONSULTATION ON INSTITUTE ACTIVITIES.—In carrying out the duties referred to in subsection (d), personnel of the Institute shall—

"(1) consult widely with representatives from private industry, institutions of higher education, and non-profit institutions; and

"(2) to the maximum extent practicable, incorporate information and perspectives derived from such consultations in carrying out such duties.

"(f) ANNUAL REPORTS.—The committee shall submit to the President an annual report on the activities of the committee under this section. Each report shall be in accordance with requirements prescribed by the President.

"(g) SPONSORSHIP.—(1) The Director of the National Science Foundation shall be the sponsor of the Institute.

"(2) The Director of the National Science Foundation, in consultation with the chairman of the committee, shall enter into a sponsoring agreement with respect to the Institute. The sponsoring agreement shall require that the Institute carry out such functions as the chairman of the committee may specify consistent with the duties referred to in subsection (d). The sponsoring agreement shall be consistent with the general requirements prescribed for such a sponsoring agreement by the Administrator for Federal Procurement Policy.".

(2) The amendment made by paragraph (1) shall take effect as of November 5, 1990.

(3) The sponsoring agreement required by subsection (g) of section 822 of Public Law 101-510, as amended by paragraph (1), shall be entered into not later than February 15, 1992.

(d) FUNDING.—(1) To the extent provided in appropriations Acts, the Secretary of Defense shall make available to the Director of the National Science Foundation, out of funds appropriated for fiscal year 1991, $5,000,000 for funding the activities of the Institute.

(2) There is authorized to be appropriated for each fiscal year after fiscal year 1991 for the Institute such sums as may be necessary for the operation of the Institute.

(3) Funds appropriated to any department or agency for the Critical Technologies Institute established under section 822 of the National Defense Authorization Act for Fiscal Year 1991, as amended by subsection (c), for fiscal year 1992 by any Act enacted before the date of the enactment of this Act shall be transferred to the National Science Foundation only for the purposes of carrying out activities of the Institute.

THE WHITE HOUSE

WASHINGTON

July 12, 1991

MEMORANDUM TO MICHAEL BOSKIN

FROM: D. ALLAN BROMLEY Allan

SUBJECT: WORKSHOP IN PUERTO RICO TO DEVELOP PLANS FOR A WESTERN HEMISPHERE GLOBAL CHANGE RESEARCH INSTITUTE

You recall that the concept of a regional global change institute was proposed during the White House Conference on the Science and Economics of Global Change last April. During the President's very successful Latin American trip last December, I had the opportunity to discuss the proposed institute, along with other science, technology and environmental issues with senior officials in Brazil, Uruguay, Argentina, Chile, and Venezuela. The meetings resulted in a good exchange of views and enthusiastic support for the institute concept in each of the five countries visited.

I asked the Committee on Earth and Environmental Sciences of the Federal Coordinating Council for Science, Engineering and Technology (FCCSET) to plan and host a scientific workshop. It will provide a forum for discussion of the concept of a regional global change institute by the countries in the Western Hemisphere.

The workshop will take place in San Juan, Puerto Rico from July 15 to July 19, 1991. We have had an excellent response to the workshop from the countries in the Western Hemisphere and expect a successful workshop. I am attaching a list of the country participants and a copy of the agenda for your information. I shall give you a report on the outcome of the workshop as soon as it is available.

THE WHITE HOUSE

WASHINGTON

October 8, 1991

MEMORANDUM FOR MICHAEL BOSKIN

FROM: D. ALLAN BROMLEY *Allan*

SUBJECT: MEETING OF THE PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY (PCAST)

The PCAST will meet Thursday, October 10, 1991. You are most cordially invited to attend. A draft Agenda is attached.

Please call Tom Welch, Executive Director, PCAST, X4692 by 1:00PM Wednesday, October 9, if you plan to attend.

Attachment

October 8, 1991

PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY

OCTOBER 10, 1991
AGENDA

<u>THURSDAY, OCTOBER 10, 1991</u>

OPEN SESSION 9:00 AM - 10:15 AM
CONFERENCE ROOM
COUNCIL ON ENVIRONMENTAL QUALITY
722 JACKSON PLACE, NW

8:30 - 9:00	ARRIVAL AND COFFEE	
9:00 - 9:15	OPENING REMARKS	DR. BROMLEY
9:15 - 10:00	TWENTY YEAR TRENDS IN THE NATIONAL ASSESSMENT OF EDUCATIONAL PROGRESS	DR. ELLIOT
10:00 - 10:15	CLOSING REMARKS AND MOVE TO ROOM 180, OLD EXECUTIVE OFFICE BUILDING	DR. BROMLEY

THURSDAY, OCTOBER 10, 1991 Continued...

CLOSED SESSION 11:30 AM - 1:00 PM
ROOM 180
OLD EXECUTIVE OFFICE BUILDING

10:15 - 10:45	PANEL PROGRESS REPORT - Education and Human Resources	DR. LIKINS DR. DRAKE
10:45 - 12:00	DISCUSSION OF PCAST PANEL DRAFT PAPER - Global Environment and Natural Resources	DR. LOVEJOY DR. BORLAUG
12:00 - 1:00	LUNCH (In Indian Treaty Room, OEOB Room 474)	

CLOSED SESSION 1:00 - 3:00 PM
ROOM 180
OLD EXECUTIVE OFFICE BUILDING

1:00 - 1:30	DISCUSSION OF PCAST PANEL DRAFT PAPER - Science, Technology and National Security	DR. BUCHSBUAM
1:30 - 3:00	PANEL PROGRESS REPORTS - High Performance Computing and Communications	DR. BUCHSBAUM DR. GOMORY
	- Bioscience and Biotechnology	DR. NATHANS DR. BORLAUG
	- Megaprojects in the Sciences	DR. MCTAGUE DR. SHAPIRO
	- International Economic Competitiveness	DR. GOMORY DR. SHAPIRO

CLOSED SESSION 3:00 - 5:00 PM
ROOSEVELT ROOM
WEST WING

3:00 - 4:30	DISCUSSION	
4:30 - 5:00	DISCUSSION OF NOVEMBER AGENDA AND CLOSING REMARKS	DR. BROMLEY

THE WHITE HOUSE

WASHINGTON

July 9, 1991

MEMORANDUM FOR MICHAEL BOSKIN

FROM: D. ALLAN BROMLEY Allan

SUBJECT: MEETING OF THE PRESIDENT'S COUNCIL OF ADVISERS ON SCIENCE AND TECHNOLOGY (PCAST)

The PCAST will meet Wednesday, July 10, and Thursday, July 11, 1991. You are most cordially invited to attend. The meeting will include some time with the President. The meeting Agenda is attached.

Attachment

PRESIDENT'S COUNCIL OF ADVISORS
ON
SCIENCE AND TECHNOLOGY

JULY 10-11, 1991
AGENDA

WEDNESDAY, JULY 10, 1991

CLOSED SESSION 1:00 PM - 5:00 PM
ROOSEVELT ROOM
WEST WING
WHITE HOUSE

1:00 - 1:15	ARRIVAL AND COFFEE (DR. BROMLEY'S OFFICE, ROOM 358, OEOB)	
1:15 - 1:30	-- Move to Roosevelt Room --	
1:30 - 1:45	OPENING REMARKS	DR. BROMLEY
1:45 - 2:00	PREPARATION FOR THIS AFTERNOON	DR. BROMLEY
2:00 - 2:30	EDUCATION AND HUMAN RESOURCES PANEL - A Progress Report	DR. LIKINS
2:30 - 3:00	THE FEDERAL COORDINATING COUNCIL FOR SCIENCE, ENGINEERING, AND TECHNOLOGY - An Update on Budget Crosscuts and Other Initiatives	MS. BACH
3:00 - 3:30	DISCUSSION	
3:30 - 3:45	BREAK	
3:45 - 4:30	MEET WITH THE PRESIDENT	
4:30 - 5:00	CLOSING REMARKS	DR. BROMLEY

THURSDAY, JULY 11, 1991

OPEN SESSION 9:00 AM - 11:15 AM
CONFERENCE ROOM
COUNCIL ON ENVIRONMENTAL QUALITY
722 JACKSON PLACE, NW

8:30 - 9:00	ARRIVAL AND COFFEE	
9:00 - 9:15	OPENING REMARKS	DR. BROMLEY
9:15 - 10:00	THE HUMAN GENOME PROJECT	DR. WATSON
10:00 - 10:15	DISCUSSION	
10:15 - 10:45	CRADAs - COOPERATIVE RESEARCH AND DEVELOPMENT AGREEMENTS - An Overview	MR. ALLEN
10:45 - 11:00	DISCUSSION	
11:00 -	CLOSING REMARKS AND MOVE TO INDIAN TREATY ROOM, ROOM 474, OLD EXECUTIVE OFFICE BUILDING Note: Please use the Pennsylvania Avenue Entrance to the OEOB.	DR. BROMLEY

THURSDAY, JULY 11, 1991 Continued...

CLOSED SESSION 11:00 - 1:00 PM
INDIAN TREATY ROOM
ROOM 474
OLD EXECUTIVE OFFICE BUILDING

11:15 - 12:00	NATIONAL SECURITY AND TECHNOLOGY PANEL - A Progress Report	DR. BUCHSBAUM
	HIGH PERFORMANCE COMPUTING AND COMMUNICATIONS PANEL - A Progress Report	DR. BUCHSBAUM
12:00 - 12:15	BREAK FOR LUNCH SETUP	
12:15 - 1:00	LUNCH	

CLOSED SESSION 1:00 - 5:00 PM
ROOM 476
OLD EXECUTIVE OFFICE BUILDING

1:00 - 1:30	GLOBAL ENVIRONMENT AND NATURAL RESOURCES PANEL - A Progress Report	DR. LOVEJOY
1:30 - 2:00	PANEL ON MEGAPROJECTS IN THE SCIENCES - A Progress Report	DR. McTAGUE DR. RATCHFORD
2:00 - 2:30	BIOSCIENCE AND BIOTECHNOLOGY PANEL - A Progress Report	DR. NATHANS
2:30 - 3:00	PCAST PANEL PROCEDURES - Legal Considerations	MS. VAN CLEAVE
3:00 - 3:15	BREAK	
3:15 - 3:45	THE S&T BUDGET - FY 1992 - FY 1993	MR. GRADY
3:45 - 4:00	DISCUSSION	
4:00 - 4:15	PANEL ON INTERNATIONAL ECONOMIC COMPETITIVENESS - A Progress Report	DR. PHILLIPS
4 15 - 4:30	UPDATE ON OMB CIRCULAR A-21	DR. HENDERSON
4:30 - 5:00	OTHER BUSINESS AND CLOSING REMARKS	DR. BROMLEY

THE CHAIRMAN OF THE
COUNCIL OF ECONOMIC ADVISERS
WASHINGTON

June 25, 1991

MEMORANDUM FOR D. ALLAN BROMLEY

FROM: MICHAEL J. BOSKIN MJB

SUBJECT: Draft Article for Science

Thank you for giving me the opportunity to comment on your draft article for Science. For the most part--with several important exceptions noted on the attached--I believe the draft provides a strong statement of views widely shared within the Administration.

The attached markup outlines my suggested revisions. Some of the suggested changes are minor and will improve the readability of the article. Others will bring the text in line with Administration policy.

I assume you will find these revisions acceptable. If any questions arise, please do not hesitate to have your staff contact Harry Broadman in my office.

Attachment

[redacted]

DRAFT

[June 18, 1991]

SCIENCE AND TECHNOLOGY IN THE BUSH ADMINISTRATION

by D. Allan Bromley

One of the most important policy initiatives of the Bush Administration -- though it has gone largely unnoticed by the general public -- has been its promotion of science and technology. If Congress enacts the President's most recent budget proposals, funding for federal nondefense research and development will have gone up over 50 percent since George Bush's election, and defense R&D will have risen about 10 percent even as growth in the defense budget has slowed. Moreover, the President has taken a number of steps to increase the coordination of federal science and technology, to consult with the private sector on federal science and technology policies, and to more fully introduce considerations of science and technology into broader policy issues. In general, the Bush Administration has been strengthening the foundations of science and technology in ways that will pay dividends for years to come.

Though he claims to have only a modest understanding of science and technology, President Bush has long been interested in these subjects. He spoke often about science and technology during his campaign, and the personnel decisions he made after his election reflected that interest. Chief of Staff John Sununu is a Ph.D. mechanical engineer; Budget Director Richard Darman has long been an advocate of federal support for science, space, and technology programs; Council of Economic Advisors Chairman Michael Boskin, a Stanford economics professor, has written often about the importance of technological development to economic growth; Roger Porter, who is the first assistant to the President with responsibility for both economic and domestic policy, has helped develop a domestic agenda that features science and technology; and Brent Scowcroft, the Assistant to the President for National Security Affairs, has a great interest in the confluence of science, technology, and national security. Furthermore, the President has put together an executive office in which the various individuals and agencies work together to an unprecedented degree, at both the staff and executive levels, on issues that extend beyond single areas of concern. Though the science advisor may have the highest visibility in the science and engineering communities, the progress now being made in science and technology would not be possible without the efforts and early planning of many other individuals within the Executive Office of the President.

During his campaign, President Bush also promised to appoint a Council of Advisors on Science and Technology, and PCAST has been meeting monthly for over a year at the White House. The President and other members of the White House senior staff sit in on portions of virtually all those meetings, providing a valuable opportunity for private sector input directly to the highest levels of the Executive Branch. The President has also greatly strengthened my position and that of the Office of Science and Technology Policy, making me the Assistant to the President for Science and Technology and nominating all four legislatively authorized OSTP Associate Directors for the first time in the office's history.

In addition, with the President's strong support, the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) has been restructured and revitalized, and the Cabinet secretaries and Directors of the departments and independent agencies involved with science and technology have become the Council's members. FCCSET is the internal, federal interagency body, with roots dating back to the Eisenhower Administration, that is charged with coordinating federal activities in science and technology that cut across the missions of more than any one federal agency. Often overlooked in the past, FCCSET has the potential to make far-reaching changes in the federal government's coordination and integration of science and technology. It can organize integrated multiagency plans in specific areas -- as it has recently done for global change, for high performance computing and communications, and for science and mathematics education, with similar efforts under way for biotechnology and for materials science and engineering -- while retaining the traditional strengths of a pluralistic R&D enterprise. It can also identify, analyze, and introduce issues ~~of~~ science and technology into other areas of federal policymaking within the White House, in the rest of the Executive Branch, and in Congress.

Bolstered by this strengthened science and technology policy apparatus, the federal government's approach to science and technology ~~has been undergoing evolutionary changes consistent with~~ a vision that President Bush and his senior advisors ~~began to~~ spell out well before his election. I would propose to illustrate such changes by looking at three broad areas of current concern: the support of academic research, the federal government's R&D portfolio, and the development of ~~a~~ federal technology policy.

The Academic Research Enterprise

The United States makes greater demands on its research universities than does any other nation, and the success of our research universities in meeting those demands has helped to build the strongest science and technology enterprise that the world has ever known. One measure of this success is the influence of the academic research enterprise compared to its overall size. According to data gathered by the National Science Foundation, colleges and universities ~~conduct~~ less than 10 percent of ~~the~~ research and development ~~done~~ in the United States (measured in terms of funding alone). Yet these institutions are the primary source of the new observations, new ideas, and new techniques that underpin the remainder of the science and technology enterprise and contribute so heavily to economic growth, to an improved quality of life, and to our national security. NSF data also indicate that academic scientists and engineers who do research as their primary or secondary work activity make up fewer than 5 percent of the total number of scientists and engineers in the United States. Yet they train virtually all future research scientists and engineers and are involved in the training of a large fraction of the scientists and engineers who become involved in activities other than research.

The importance of the academic research enterprise to the nation's future prosperity and security is reflected in the funding trends of the 1980s. Total R&D expenditures at colleges and universities rose from $6 billion in 1980 to $14 billion in 1989, an increase of over 50 percent in constant dollars. Over that same period, federal funding of R&D at academic institutions rose from about $4 billion to about $9 billion (35 percent in real terms); therefore, other sources of funding -- state and local governments, industry, and the institutions' own funds -- rose even faster than did federal spending. As a result of these increases, more researchers are now being supported at the nation's colleges and universities than have ever been supported in history.

It may seem paradoxical, given these increases in funding, that the academic research community should consider itself to be in a state of acute distress, with some commentators suggesting that the future vitality of the enterprise is at stake. There appear to be several interrelated factors at play. First, we are undoubtedly the victims of our own success. Progress in research has generated an unprecedented number of opportunities in science, and our success at training academic researchers has produced many young people who are more than ready to grasp those

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opportunities. Though available levels of funding have increased, the numbers of opportunities and researchers have increased even faster.

A number of other, interrelated factors have also increased pressures on academic researchers. Larger numbers of researchers are submitting multiple proposals and amended proposals, creating a proposal pressure that has stressed the peer review system. In addition, the decision at NIH to lengthen the duration of grants, a decision endorsed by investigators, has created outyear mortgages that have reduced funding for new awards and new investigators. In some areas, the costs of doing increasingly sophisticated research have gone up faster than the usually quoted Consumer Price Index (CPI) rate of inflation. New organizational arrangements in research universities, such as the greater use of nonteaching researchers and the development of the "entrepreneurial" principal investigator, have created structural stresses on the system. New but necessary regulations have brought increased administrative costs, which have further drained funds from the support of research. Obviously, given the complexity of the issues involved, there can be no simple solutions to these problems.

The economic and social utility of research should be kept in mind. A recent study by the distinguished economist Edwin Mansfield of the University of Pennsylvania calculated the social rate of return on federal support of academic research to be in the 25 to 40 percent range. (The social rate of return is defined as the benefits that producers and consumers receive from new products and processes, including those benefits not reflected in market prices.) This economic indicator is a very important one, and one that the science and engineering communities have long needed.

It is essential, however, that potential or actual rate of return not obscure the other important rationales for both fundamental and applied research. Such activities -- pushing back the frontiers of human ignorance -- are among the greatest challenges(?) adventures available to our species. They are integral parts of our culture and are part of what separates us from all other species on our planet.

The Bush Administration, recognizing the pivotal role of academic research, has moved forward on two broad fronts to strengthen this component of the R&D system. First, it has proposed substantial increases for the federal support of university-based research, and these increases have been structured with particular emphasis on individual investigators. Of the 18 percent increase requested for the National Science Foundation in the President's FY 1992 budget request, over 80 percent would go directly to individual investigators and their research infrastructure. At the National Institutes of Health, FY 1992 funding for research project grants is slated to grow by 9 percent while the overall NIH budget grows by 6 percent. And at a time of declining defense budgets, the Department of Defense's University Research Initiative has been protected from budget cuts.

The Bush Administration is also committed to ensuring that the mechanisms of federal support for academic research are the most appropriate ones for the needs of the nation and the needs of the research universities. Within the Executive Office of the President and through FCCSET and PCAST, the Administration has been conducting a broad analysis of the mechanisms of federal support for academic research. For example, through a Working Group on the Structure of Science Support, FCCSET has been examining historical trends in federal R&D funding by the purpose of that funding and the mode in which it is distributed. This analysis will be used by FCCSET to provide input to policy discussions concerning future directions in federal support.

One of the important distinctions being examined by the FCCSET working group has been that between disciplinary research and thematic research. The working group defines disciplinary research as research driven entirely by the pursuit of knowledge and by individual curiosity. This research typically takes place within formal academic disciplines and is guided by the history and traditions of that discipline.

Thematic research, on the other hand, is guided by a particular goal or national need, such as the need to understand global climate change, the goal of deciphering the human genome, the economic promise of high performance computing, or the challenge of confronting the AIDS epidemic. Thematic research is not necessarily applied or strategic research, since basic or fundamental research is integral to addressing these needs. But it is driven by factors other than the pure intellectual curiosity of the researcher and generally cuts across a number of scientific disciplines, including those of the social and behavioral sciences.

According to the working group, support for thematic research at universities has grown faster during the 1980s than has that for disciplinary research in some areas. [We are trying to get overall numbers from the working group, though they may not be available for several months.] In part, this reflects the increasing integration of science and technology into our society and the demand that science and technology address important regional, national, and international needs. For example, the U.S. Global Change Research Program and the high performance computing and communications initiative, which are both highlights of the 1992 budget submission, constitute an acceleration of this trend. However, the increasing role of thematic research may also contribute to the frustration felt by many in the disciplinary research community.

Disciplinary research remains an absolutely vital component of the research system because it is the most fruitful source of new knowledge in science and because it exerts very effective quality controls on the rest of the system. At the same time, thematic research has become an essential source of the knowledge needed to address many of today's most pressing national and international problems. The challenge for policymakers, administrators, and researchers is to balance these two types of activity to best serve the public interest.

The Government's R&D Portfolio

Achieving balance within the academic research community is just one aspect of a much broader process of evaluation and priority setting that goes on continually within the federal government. Support for academic research and development constitutes only about a third of the federal government's total support for nondefense R&D (and less than a sixth of the government's support for both civilian and defense R&D, including about $1 billion of defense money that goes to universities). The rest goes toward a tremendously diverse set of other activities, from small grants for work conducted in nonacademic settings to the work of the national laboratories to large projects that serve broad groups of researchers, often referred to as megaprojects.

These megaprojects are especially visible within the scientific community and to the general public, but there are many difficulties in using them to draw a sharp distinction between large science and small science. Large projects include both single facilities (the Superconducting Super Collider) and coordinated programs of research being done by individual investigators (the Human Genome Project). Some large projects pursue disciplinary research (e.g., telescopes or light sources) while others are focused on thematic research (the U.S. Global Change Research Program).

The large projects now being undertaken will provide the tools that individual investigators will need to reach the frontiers of their fields five or ten years down the road. The people who will use these facilities are typically individual faculty members with a few assistants and/or students, and their research will be indistinguishable from that done in other locations. The projects are initiated from the bottom up, through proposals submitted by groups of researchers to the appropriate federal agencies.

Many people both inside and outside of the scientific community have called for these projects, together with the ensemble of all science R&D activities, to be judged by a given set of criteria and assigned a priority, presumably so that items can be cut from the bottom of the list when funding is short. In fact, it is not meaningful to rank order these projects in any one-dimensional linear array. Different categories of R&D activities must be judged by different selection and evaluation criteria. Disciplinary research projects, for example, are selected primarily on the basis of their scientific merit to the discipline in question, whereas thematic projects are selected for the combined scientific merit and relevance to the overall goals of the program.

Other large projects, such as the space station and the Moon-Mars Initiative, have never been primarily science projects, though for the purposes of the budget they may be categorized entirely as research and development. Rather, they are justified primarily on the basis of such considerations as exploring physical frontiers, inspiring students to enter science and technology, or maintaining national leadership in a given area.

The vast majority of defense R&D is judged by yet another set of criteria -- the need to develop, test, and evaluate new and improved weapons and support systems. Less than 10 percent of the Defense Department's R&D budget goes for basic and applied research that can be judged by many of the same criteria applied to nondefense R&D. In this sense, it can be misleading to compare the relative size of the defense and nondefense R&D budgets; the more relevant question is whether each category of support is enough to meet national needs.

In providing for the nation's security, we need a defense research base that will guard against technological surprise and will keep the United States in the lead in uncovering the rare revolutionary technology breakthroughs that define tomorrow's military advantage. The defense community also needs an effective means of sustaining and exploiting evolutionary improvements in weapons technologies.

As Desert Storm reminded us, America's tremendous scientific and technological strength provides the qualitative edge that has long ensured the nation's deterrent and helped preserve the peace. The conflict in the Gulf, the dramatic developments under way in Eastern Europe, and the continuing uncertainty in the Soviet Union presage far-reaching changes in the international environment and in the security needs of the West. With the globalization of technology and the spread of weapons of mass destruction, even a relatively undeveloped society can threaten the United States and its allies. The development and application of technology to support changing defense, foreign policy, and intelligence requirements are central Bush Administration concerns.

Currently a PCAST panel is examining the appropriate roles of science and technology for national security in the vastly changed international situation that has developed over the past eighteen months. OSTP and NSC are cooperating to provide support for this panel.

Because of the different criteria used to judge various R&D activities, the budget submitted by the President to the Congress each year should not be seen as a list of projects ranked by priority (although a cascade of priority decisions enter into the budget). Rather, it is best viewed as the Administration's attempt to achieve the most effective and balanced R&D portfolio possible. In the process, the Executive Office of the President -- and particularly OMB and OSTP -- have a unique opportunity to examine the entire R&D budget and address the critically important issue of overall balance among its components. Along the way, many difficult choices must be made. Excellent projects in worthy fields may need to be delayed or abandoned because they do not contribute as much to the whole as does some other project. Any one project may contribute to several objectives,

isn't CEA involved?

or a project that may not be of "high priority" by itself may play a critical role in balancing the portfolio.

OMB, working closely with the federal agencies, clearly bears the primary responsibility for the development of the President's budget. OSTP provides input and advice throughout the process in matters relating to science and technology, as does the Council of Economic Advisers on matters relating to economic policies. Final decisions on matters that have not been resolved at lower levels in the system are quite properly made by the President.

If Congress mandates a different level or allocation of R&D funding than the President has proposed, I would argue that it should do so in ways that maintain the overall balance of the R&D portfolio. For example, cutting a large project from the R&D budget can seriously skew the distribution of resources and personnel. The Congress and Administration must work closely together in maintaining the health and integrity of the R&D enterprise.

Another Congressional action that can distort the distribution of R&D resources is the unrequested appropriation of funds for specific R&D projects or facilities -- a practice commonly known as earmarking. According to an analysis of the FY 1991 budget conducted within my office, about $427 million was appropriated for such projects at universities in 1991. Earmarked projects typically do not undergo merit review, and thus their potential for contributing to scientific progress is often unknown. In the present era of tight budgets and spending caps, earmarking has the effect of substituting projects of unknown scientific merit for ones that have had careful examination of their scientific merits and thus threatens to weaken the nation's R&D effort.

The impossibility of prioritizing all forms of science and technology according to a single set of criteria does not imply that more focused prioritizations are not useful. In particular, priority setting by the scientific and engineering communities is an invaluable aid in establishing a balanced R&D portfolio. In recent years, several subdisciplines and some disciplines within science and engineering have been able to establish priorities within their fields. For example, the astronomers and astrophysicists have recently produced an excellent list of priorities under NAS sponsorship, as did the physicists in an earlier survey in the 1970s. Now the need is for scientists to establish priorities within broader disciplines -- and to contribute to the inevitably political task of setting priorities across disciplines.

In preparing its budget, the Administration must also strike a balance between R&D activities and the other functions of government. Research and development now account for about one seventh of the total domestic nondefense discretionary spending; the President is proposing that this fraction be increased. In the FY 1992 budget, for example, he proposed a 13 percent increase in R&D, despite the overall domestic discretionary spending being capped at roughly the rate of inflation by last year's budget agreement. Frank Press, in a recent article in the Boston Globe, described the budget as having "stronger support for science than any in recent memory." However, in what is effectively a zero sum game (in constant dollars), the R&D component is very visible and very vulnerable to attack by other strongly motivated, competing constituencies.

The shift of funds from consumption to investment that is reflected in the Bush Administration's support of R&D represents an important aspect of the Administration's commitment to what the President has termed "the next American century." Politically, such a shift will not be easy to accomplish -- as I shall describe below -- but the commitment marks an important step in the federal government's view of its responsibilities.

[A re-typed (heavily edited) version of Federal Technology Policy section follows p. 16 below]

Federal Technology Policy

The federal government provides much more support for applied research and technology development than it does for basic research. This work is largely directed toward meeting the federal government's own needs and the needs of the public in such areas as defense, space, health, and environmental protection. But this work, together with the basic research that underlies it, is also important to the public sector in developing the new products and processes that fuel economic growth.

Because of the importance of technology to the goals of both the public and private sectors, the Bush Administration has taken a number of steps to strengthen its development and deployment. It has sought to create a financial environment that is conducive to longer-term investment in technology, through lowering the federal budget deficit, proposing to cut the capital gains tax, and protecting intellectual property through international negotiations. It has encouraged technology transfer and research cooperation, particularly involving small and mid-sized companies. It has sought to remove legal and regulatory barriers to innovation and private sector investments in research and development. It has proposed making the research and experimentation tax credit for private firms both permanent and more broadly applicable. And it has focused on education, which is perhaps the single most important factor in ensuring the long-term competitiveness of our nation's industries.

not a very rich statement

The federal government's support of research and development is an integral part of its technology policy. Through its support of basic research, it helps generate the new knowledge that will lead to future technologies and helps train the scientists and engineers who will develop and use those technologies. The federal government also has a role in supporting research on generic, precompetitive technologies that have the potential to contribute to a broad range of government

(regulatory
[illegible] consortia

and commercial applications. The government's rationale for investing in these technologies is essentially the same as that for investing in basic research -- namely, that while the benefits of these technologies are widespread in society, no single firm can appropriate enough of the returns to justify -- by itself -- an adequate level of investment.

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 investigations 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 work.

Specific examples of precompetitive technologies can be found in the initial round of awards made by the Advanced Technology Program, which is administered by the National Institute of Standards and Technology within the Department of Commerce. Eleven projects were selected (Table 1) out of 249 proposals received (totaling $122 million in requests for the first year). These projects were selected after a rigorous peer review process involving both technical and commercial assessments. They will receive $9.2 million in federal funds during the first year, with the companies contributing more than 50 percent of the total cost.

An obvious question is why the federal government should fund even part of the cost of these projects. The answer is that these projects would very probably not be done at all if left to private industry. Some are too far from commercial development for their commercial potential to be assessed. For others, individual firms cannot capture enough of the benefits to justify the necessary investment. With federal cost sharing, however, the risks can be shared and the expertise of private industry can be tapped to select promising commercial technologies.

At the same time, the federal government does not believe that it has an appropriate role in targeting particular this is too downstream for gov't support

industries ~~for support~~ or particular technologies for support. ~~commercialization~~. The private sector has the principal role in innovation and in identifying and developing technologies for commercial products and processes. Even in meeting the government's own needs, the government relies primarily on the private sector to undertake the development process and encourages these activities to be managed in such a way as to allow commercial applications of the resulting R&D.

The Advanced Technology Program is just one element in a wide-ranging federal approach to civilian and defense technology development. Other elements include the Engineering Research Centers, Science and Technology Centers, and Industry/University Cooperative Research Centers sponsored by the National Science Foundation; support of SEMATECH, the National Center for Manufacturing Sciences, and other partnerships led by the private sector to advance technology development; the Regional Manufacturing Technology Centers run by the Department of Commerce and other outreach efforts designed to reduce the barriers to the adoption of new technologies; and more widely based efforts at the over 700 federal laboratories to encourage technology transfer from the government to private industry.

In particular, the federal laboratories and their staffs represent a unique American resource of know-how, technology, and facilities. We have been less successful than we might have been, however, in exploiting this resource in support of national goals. The coupling between the laboratories and the private sector -- particularly small and mid-sized businesses -- has been less than would have been desirable, although substantial progress has been made in recent years.

This is particularly the case at the input end of the decision-making process in the laboratories. While many laboratories have rather elaborate visiting committee mechanisms that bring distinguished members of the academic and industrial sectors into the laboratories to provide overall quality control and peer review of the research products and programs, such external bodies have little, if any, influence on the selection of those research projects that are actually undertaken and those that are, for whatever reason, passed over. If such consultations were introduced at the outset, the probability of external interest in, and eventual use of, the products of research would be substantially enhanced.

What Scientists and Engineers Can Do

In general, the Bush Administration has laid out what we believe to be a coherent and forward-looking science and technology policy. But the Administration is just one actor among many -- including Congress, the science and engineering communities, and the public -- that determine the nation's overall science and technology policy. It is in the interaction among these constituencies that the nation's approach to science and technology is forged.

One thing that continually amazes me about our system of government is how truly representative the system is, at both the executive and legislative levels. Political decisions are rarely made without a substantial base of consensus. As Benjamin Franklin once said, "In America the people govern -- if they want to."

According to the National Science Foundation, there are more than 5 million scientists and engineers in the United States -- numerically more than three times the number of American lawyers and physicians combined. There is no reason why this group cannot be as effective a constituency as the much smaller groups that successfully promote other forms of federal spending. But effective advocacy will require a fundamental shift in the attitudes of scientists and engineers. Scientists and engineers can no longer sit at home or in their laboratories and trust that someone in Washington will eventually realize how important their work is to the future of the nation. There are too many other

REPLACEMENT FOR FEDERAL TECHNOLOGY POLICY SECTION

Federal Technology Policy

Because of the importance of technology to the public and private sectors, the Bush Administration has taken a number of steps to strengthen its development and deployment. We believe that the private sector has the principal role in innovation and in identifying and developing technologies for commercial products and processes. Therefore, technology development and deployment is served, first and foremost, by the creation of a economic environment that is conducive to longer term investment in technology. Major efforts in this regard include initiatives to lower the Federal budget deficit and to cut the capital gains tax. We have also proposed to make the research and experimentation tax credit for private firms permanent and to apply this credit to a broader range of activities. Total R&E credits provided to support technology development under current law were $x.x billion in 19xx.

Efforts to establish economic conditions conducive to R&D activities must be complemented by steps to improve other aspects of the environment for investment in technology. The Administration has vigorously pursued the protection of intellectual rights in international negotiations. It has encouraged technology transfer and research cooperation, particularly involving small and mid-sized companies. It has sought to remove legal and regulatory barriers to innovation and private-sector investments in research and development. And it has emphasized the need to improve education, which is perhaps the single most important factor in ensuring the long-term competitiveness of our nation's industries.

The Federal Government's direct support of research and development is another integral part of its technology policy. Through its support of basic research, government helps generate the new knowledge that will lead to future technologies and helps train the scientist and engineers who will develop and use those technologies. Federal funding for basic research is supplemented by the larger amount of resources devoted to applied research and technology development. This work is largely directed toward meeting the Federal Government's own needs and the needs of the public in such areas as defense, space, health, and environmental protection. Even in meeting the Government's own needs, the Government relies primarily on the private sector to undertake the development process and encourages these activities to be managed in such a way as to allow commercial applications of the resulting R&D. This work, together with the basic research that underlies it, can be important to the private sector in developing the new products and processes that fuel economic growth.

The Federal Government does not believe that it has a role in targeting particular industries or particular technologies for support. However, the Federal Government does have a limited role in supporting research on generic, precompetitive technologies that have the potential to contribute to a broad range of government and commercial applications. The Government's rationale for investing in these technologies is essentially the same as that for investing in basic research -- namely, that while the benefits of these technologies are widespread in society, no single firm or consortia of firms can appropriate enough of the returns to justify an adequate level of investment. (In some cases, the removal of antitrust restrictions on research cooperation alone will provide a sufficient incentive for adequate research investment.)

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 investigations can be shared by a group of companies without reducing the incentives for any of them to further development competitive proprietary products based on the work.

Specific examples of precompetitive technologies can be found in the initial round of awards made by the Advanced Technology Program, which is administered by the National Institute of Standards and Technology within the Department of Commerce. The projects selected will receive $9.2 million in Federal funds during the first year, with the companies contributing more than 50 percent of the total cost.

The Advanced Technology Program is just one element in a wide-ranging Federal approach to technology development. Other elements include the Engineering Research Centers, Science and Technology Centers, and Industry/University Cooperative Research Centers sponsored by the National Science Foundation; support of SEMATECH, the National Center for Manufacturing Sciences, and other partnerships led by the private sector to advance technology development; the Regional Manufacturing Technology Centers run by the Department of Commerce and other outreach efforts designed to reduce the barriers to the adoption of new technologies; and more widely based efforts at the over 700 Federal laboratories to encourage technology transfer from the Government to private industry.

In particular, the Federal laboratories and their staffs represent a unique American resource of know-how, technology, and facilities. We have been less successful than we might have been, however, in exploiting this resource. Coordination between the laboratories and the private sector -- particularly small and mid-sized businesses -- has been less than would be desirable, although substantial progress has been made in recent years.

This is particularly the case at the input end of the decision-making process in the laboratories. Many laboratories have elaborate visiting committee mechanisms that bring distinguished members of the academic and industrial sectors into the laboratories to provide overall quality control and peer review of the research products and programs, such external bodies have had little, if any, influence on the selection of those research projects that are actually undertaken. If such consultations were introduced at the outset, the probability of external interest in, and eventual use of, the research products would be substantially enhanced.

claimants for federal funds, almost all of them with what may well appear to be more immediate needs than those represented by the long-term investments required for science and technology.

Congress has been extremely foresighted in funding science and technology, and many members of Congress agree with the Administration that this nation is underinvesting in research and development. But Congressmen are under intense pressure from a large number of groups, and in the tight budget climate of the next few years they are going to have to make difficult decisions. Scientists and engineers must make their voices heard if the promise of science and technology is to be realized. Representative George Brown, chairman of the House Science, Space, and Technology Committee, was once asked if scientists and engineers tend to forget who their congressmen are at election time. "Forget?" Brown answered. "They don't know who they are in the first place." Any scientist or engineer who cannot pass this simple test of political literacy has very little right to criticize federal actions affecting science and technology.

At the same time, the federal government supports less than half of the research and development conducted in this country, which argues for a very broad-based approach to public outreach. I believe that every scientist, regardless of his or her position, should view public education as part of his or her job description. This broad civic responsibility is not expected of other professions. But science and technology demand an unusual measure of public involvement, both because of the public's support for these activities and because of the broad influence of these activities on the public.

I believe that we are about to enter a period of unprecedented productivity for science and technology. More than ever before, science and technology will be key elements in addressing a broad range of national issues, from defense to health to competitiveness to education. The Bush Administration recognizes the contributions that science and technology can make to these problems, and it is taking steps to ensure that the appropriate science and technology will be available to meet the challenge.

Table 1 Initial Round of ATP Awards

Project	Applicant
Single Applicants	
Precision optics for soft X-ray projection lithography	AT&T Bell Laboratories
Computer interface for cursive handwriting recognition	Communication Intelligence Corp.
Nonvolatile magnetoresistive semiconductor technology	Nonvolatile Electronics, Inc.
Tunable UV/VUV solid state laser	Light Age, Inc.
Machine tool compensation techniques	Saginaw Machine Systems, Inc.
Thallium superconductor thin film processing	Du Pont Company
Joint Ventures	
Printed wiring board interconnects	National Center for Manufacturing Sciences
Holographic mass storage	Microelectronics and Computer Technology Corporation
Flat panel display manufacturing	Advanced Display Manufacturers of America Research Corporation
Solid state laser technology for point source X-ray lithography	Hampshire Inc., and McDonnell Douglas Electronic Systems Co.
Short wavelength sources for optical recording	National Storage Industry Consortium

Document originally attached to following page.

THE WHITE HOUSE
WASHINGTON

6/5/91

TO: MICHAEL BOSKIN

FROM: **PHILLIP D. BRADY**
Assistant to the President and
Staff Secretary

The attached has been forwarded to the President

THE WHITE HOUSE

WASHINGTON

91 JUN -4 PM 3:41

June 4, 1991

MEMORANDUM FOR THE PRESIDENT

FROM: D. ALLAN BROMLEY Allan

SUBJECT: President's Council of Advisors on Science and Technology Views on Your Fiscal Year 1992 R&D Budget Request

Mr. President, since we were unable to meet with you at our May meeting, your Council of Advisors on Science and Technology, would like to present you with memoranda on their consensus views of issues of National importance.

The first of these is the research and development portion of your the Fiscal Year 1992 Budget. Council member John McTague has taken the initiative to articulate the Council's recommendations.

The PCAST would be most pleased to discuss with you this topic and these recommendations if you so desire.

Attachment

THE WHITE HOUSE

WASHINGTON

91 JUN -4 PM 3:41

June 4, 1991

MEMORANDUM FOR THE PRESIDENT

JMT.

FROM: JOHN McTAGUE, ON BEHALF OF PCAST

SUBJECT: Investing in the Future - Follow Through With Congress

The Council reiterates its support for the important investment in the future proposed in your FY 1992 Budget submission, particularly in the areas of research and development. At the March PCAST meeting you noted the lack of a natural political constituency for research, especially individual investigator efforts. This makes all the more important strong Administration follow-up with the Congress, particularly as consideration moves to the appropriation process.

From the authorization hearings and budget resolutions to date, it is becoming increasingly clear that sustaining your R&D priorities will require your personal and visible participation. If a White House meeting were called together, with both Republican and bipartisan Congressional leaders to highlight the priority this investment has for the nation, it would be particularly effective. The Council recommends such an action, realizing the many demands on your time and political capital.

Michael — Have this? Dick

THE WHITE HOUSE

Office of the Press Secretary

For Immediate Release May 14, 1991

STATEMENT BY
DR. D. ALLAN BROMLEY
ASSISTANT TO THE PRESIDENT FOR SCIENCE AND TECHNOLOGY AND
DIRECTOR, OFFICE OF SCIENCE AND TECHNOLOGY POLICY

Recent press reports have suggested that the Administration's policy on Federal support of technology development has changed. These reports have also linked this alleged policy changes to internal disputes involving, among others, the Chief of Staff, the Director of the Office of Management and Budged, the Chairman of the Council of Economic Advisors, and myself. While I am proud of the role OSTP has played in this Administration, a role that reflects the importance the President attaches to science and technology as wellsprings of economic growth, these reports are simply false.

This Administration's basic policy principles in this area were developed during the 1988 campaign and have not changed. In February, 1989 (before I was even nominated for my current position) the President stated (Building a Better America, p. 36):

> The Federal investment in R&E should focus on basic research and allow the private sector ... to decide which technologies have the most potential in the

marketplace. The economy must provide a climate which encourages businesses to take risks and invest in new, bold technologies.

To these ends, the President proposed to double the budget of the National Science Foundation and renewed his calls for making the Research and Experimentation (R&E) Tax Credit permanent and for cutting the capital gains tax rate. In his 1990 Economic Report (p. 5), he stated his intention to continue to press "for increased Federal support of research with widespread societal benefits and that private firms would not have adequate incentives to undertake" and reaffirmed his opposition "to any sort of industrial policy in which the government, not the market, would pick winners and losers."

These basic policies have been and are still supported by all members of this Administration. They were reiterated in the report "U.S. Technology Policy," issued in September, 1990. To be worthy of Federal support, any research project must have potential benefits that are so widespread that no private firm would have an incentive to finance the project, and the project must of course pass a careful social cost-benefit test. I have been personally gratified by the strong support for fundamental research that has resulted from the application of this standard by the President's budget review committee, which includes the

Chief of Staff, the Director of the Office of Management and Budget, and the Chairman of the Council of Economic Advisers.

One apparent source of this confusion in the press has been the report of the National Critical Technologies Panel, issued on April 25, 1991. This report was mandated by legislation passed in 1990. The Administration does not endorse that legislation's premise that certain technologies can be identified as "critical," and the report itself does not reflect the views of the Administration. The views of this independent panel will of course be considered, along with the views of others, in making scientific recommendations for Federal research support.

But it should be clearly understood that neither that report nor recent press reports signal any change in the Administration's basic policies in this area. The President supports Federal investment in fundamental research and the creation of a climate in which private innovation can flourish but continues to oppose any form of industrial policy. And he expects all members of his Administration to adhere to this policy.

Draft 5-14-91, 9:30 AM

Proposed Letter to the Editor, Wall Street Journal

On April 25, 1991, the National Critical Technologies Panel presented to Congress a report describing 22 technologies considered critical for national security and economic prosperity. Since then a number of articles (e.g., Bob Davis, WSJ 5/13/91) have appeared in the news media claiming that the Administration's policies toward Federal support of technology development have changed. In fact, if the authors of these articles would have examined the history of the issue in more detail, they would have found that the Administration's policies have not changed. Since the 1988 campaign the President and his Administration have highlighted the importance of innovation and new technologies, their impact on economic growth and improvements in the quality of life, and the importance of reducing barriers to innovation caused by regulations.

The policies of the Administration have been entirely consistent with the view stated by President Bush in March 1990 in an address to the American Electronics Association: "This Administration is committed to working with you in the critical precompetitive development stage where the basic discoveries are converted into generic technologies that support both our economic competitiveness and our national security. Here again we can help to level the international playing field on which you compete." More recently, the Vice President has said that: "One of the key lessons we learned from the Gulf War is that technology is critical to our national security. For America to be number one in technology and commercialization of related products, we must have a healthy entrepreneurial climate for private sector development of technology."

Other policy statements have also pointed out that the Federal government should participate with the private sector in precompetitive research on generic, enabling technologies that have the potential to contribute to a broad range of government and commercial applications. We have not departed from this position.

The Administration does not support "industrial policy" in any form, as the article of May 13 implied. Support for precompetitive, generic technologies is different from supporting particular industries or companies. In the latter case, the Federal government would become a force in the marketplace and predetermine who is going to succeed and who is not. Such actions are likely to result in reduced efficiency, slower productivity growth and a lower standard of living. Economies in other areas of the world have experienced such adverse effects from government intervention and control.

The appropriate role of the Federal Government is to provide necessary support for the development of precompetitive, generic technologies that can benefit the entire economy but that would otherwise go undeveloped because they do not offer sufficient return for any single company. In addition, the Federal government must foster a stable economic environment leading to increased investments and reduced uncertainty in the business environment. Finally, the Federal government can assist by removing barriers to the efficient functioning of marketplaces, including legal and regulatory barriers.

The National Critical Technologies Panel was created in response to legislation passed in 1990 and sponsored primarily by the Senate Armed Services Committee. It was an independent technical panel consisting of seven government and six private sector members and not an internal White House panel. In its report, the panel did not advocate changes in federal policy. Rather, it noted the importance of basic scientific research as the underpinnings of technology, and pointed out that both the public and private sectors have to place greater emphasis on the imaginative exploitation of this country's vast knowledge base.

On the same day that the National Critical Technologies Panel made its report, the Vice President's Council on Competitiveness issued a fact sheet which summarizes Administration policies in support of technology development in America. It covers a range of topics, but with more detail on the legal and regulatory climate.

The aggregate message represented by these policy statements is clear: The Administration is committed to enhancing economic competitiveness, national security, and the quality of life for all Americans; and it will do so by working with the private sector. Our society possesses many strengths and assets that can be mobilized within our basic system of free enterprise.

Report of the

National Critical Technologies Panel

March 1991

The National Critical Technologies Panel
1101 Wilson Boulevard, Suite 1500
Arlington, Virginia 22209

March 22, 1991

The President
The White House
Washington, D.C. 20500

Dear Mr. President:

On behalf of the National Critical Technologies Panel, I have the honor to present this first biennial report as required by Title VI of Public Law 94-282, as amended by Section 841 of Public Law 101-189. It describes 22 technologies considered essential for the United States to develop in the interests of the Nation's long-term security and economic prosperity.

We most recently have been reminded, by the spectacular performance of U.S. and coalition forces in the Persian Gulf, of the crucial role that technology plays in military competitiveness. It is equally clear that technology plays a similar role in the economic competitiveness among nations.

Almost all of the critical technologies identified by the Panel are essential to national defense as well as economic prosperity. In fact, there is a substantial overlap between these technologies and those deemed critical by the Department of Defense in its 1990 Report to Congress on this subject. Much of the research and development activity directed toward these generic technologies will indeed serve a dual purpose.

As a follow-on to this report, subsequent panels will refine and update this analysis. It is hoped that the report and its future editions will help to increase awareness of the crucial role of technology in achieving our national goals.

Sincerely,

William D Phillips

William D. Phillips
Chairman
National Critical Technologies Panel

Enclosure

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REPORT OF THE NATIONAL CRITICAL TECHNOLOGIES PANEL

MARCH 1991

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ABSTRACT

Twenty–two technologies deemed critical to the national economic prosperity and to national security have been identified. The selection of national critical technologies was carried out by a panel appointed by the Director, Office of Science and Technology Policy, Executive Office of the President. The study was authorized by the Fiscal Year 1990 Defense Authorization Act and will be updated biennially through the year 2000.

Each selected technology is discussed separately in the report with respect to scope, basis for selection, and international trends. A major conclusion of the study is that technology alone cannot ensure economic prosperity and national security. Technology can make an important contribution to the future of U.S. national interests, but only if we learn to utilize it more effectively.

NATIONAL CRITICAL TECHNOLOGIES

"If America is to maintain and strengthen our competitive position, we must continue not only to create new technologies but learn to more effectively translate those technologies into commercial products."

President George Bush
November 13, 1990

INTRODUCTION

The timely development and deployment of technologies is essential to satisfy such national needs as defense, economic competitiveness, public health, and energy independence. Identification of technologies for concentration of effort becomes, therefore, a matter of considerable importance. In this report, 22 technologies deemed critical to the satisfaction of national needs have been identified.

The underpinnings of technologies reside in the basic sciences. The unmatched science base that the United States possesses today is the result of patient and judicious public and private sector investment in the basic sciences in the decades following World War II. However, the scientific discoveries that spark technological development are unpredictable with regard to both timing and content. Therefore, support for the basic sciences needs to be broadly based in order to maximize the yield of useful advances that ultimately can be translated into technologies. In contrast, technology development and deployment, because of the time and resource commitments involved, require a greater selectivity and concentration of resources than is appropriate for the basic sciences.

In a study of this nature, criteria have to be developed for selection of critical technologies based on factors such as vulnerability and pervasiveness (see Table A–2, Appendix A). Once this is done, technologies can be selected to match the range of defined needs, bearing in mind that any finite list will contain elements of subjectivity. The "critical" technologies identified in this report are closely related to those identified in other independent studies (see Table 2). The critical technologies identified herein are set forth with the confidence that they constitute appropriate bases for exploitation to satisfy many of the nation's future needs. This initial report is intended to highlight the importance of these critical technologies in meeting future national needs and to point out opportunities for public and private sector investments and actions. Future Panels will prepare biennial updates to ensure that the National Critical Technologies compilation reflects current technologies and national needs. The views expressed in this report are solely those of the National Critical Technologies Panel.

Technology and The Future

In an environment of intensifying global competition, deployment of technology is becoming the strategic battlefield of the international marketplace. Increasingly, successful firms are not necessarily the discoverers and developers of the latest innovation, but are those that are able to swiftly bring associated products to market. The proliferation of integrated product and process design tools only serves to reinforce the trends toward shorter product cycles and unceasing incremental innovation.

The key to future U.S. competitive success involves a fundamental change in the way U.S. industry competes in the marketplace. U.S. research institutions and businesses must place greater emphasis on deployment of new technologies. Moreover, discovery, development, and deployment must be integrated and viewed as concurrent rather than sequential activities. U.S. industry must be infused, from the boardroom to the factory floor, with a relentless desire to constantly improve both product and production methods. In selecting the National Critical Technologies, the Panel has placed a special emphasis on the creation of new products and on the processes to produce them. This entails an integrated approach to manufacturing process and product design, performance, quality, and cost.

This integrated approach applies equally to the defense and commercial sectors of the economy. Technology superiority has long been recognized as a fundamental element of military power. The recent Persian Gulf War serves as a reminder of the important role advanced technology plays in maintaining our national security. With declining defense budgets accompanying rapid increases in the pace of technological innovation, the ability of U.S. industry to translate technology advances into affordable, high-quality, high-performance military systems will remain an important national priority.

Technology alone cannot ensure economic prosperity and national security. It can make an important contribution, but only if we learn to utilize it more effectively in the development of innovative, high-quality, cost-competitive products. While continuing to maintain a strong science base, the United States must place greater emphasis on the imaginative exploitation of its knowledge base.

THE NATIONAL CRITICAL TECHNOLOGIES

The National Critical Technologies Panel, appointed by the Director, Office of Science and Technology Policy, Executive Office of the President, includes senior Federal agency and private sector officials who are responsible for technology development and application. (Panel membership is shown in Appendix A.) The Panel identified a set of technologies that reflects the full range of national technology needs. The 22 technologies selected fall into six broad areas:

- **Materials** with properties that promise significant improvement in the performance of items produced and used by virtually every sector of the economy
- **Manufacturing** processes and technologies that can provide the basis for industry to bring a stream of innovative, cost-competitive, high-quality products into the marketplace
- **Information and Communications** technologies which continue to evolve at a breath-taking pace, permanently changing our approaches to communication, education, and manufacturing
- **Biotechnology and Life Sciences** advances that will permit unconventional approaches to major problems in such diverse fields as medicine, agriculture, manufacturing, and the environment
- **Aeronautics and Surface Transportation** systems that enhance our civilian and military capabilities and increase the ease and safety of travel
- **Energy and Environment** related technologies which have the potential to provide a safe, secure, and enduring sources of energy and ensure that a healthy environment is preserved for the use of future generations.

Nearly 100 separate technologies were nominated by the Panel for consideration. Based on selection criteria and extensive private sector and government input, the Panel selected the 22 they considered the most important. Some technologies (such as fusion energy) were not included in this list because the benefits of the technology will be realized only in the longer term. In other cases (such as signature control), the technology is important but restricted, and it was deemed to be more appropriately handled in other, more narrowly focused planning efforts such as the DoD ***Critical Technologies Plan***. The National Critical Technologies selected by the Panel are listed in Table 1.

The Panel addressed technologies directed primarily at enhancing national security and economic competitiveness. There are other national goals not addressed in this report for which different enabling technologies may be required, for example, manned space exploration. However, space exploration will continue to stimulate a broad range of advances in both the aerospace and non-aerospace industries, contributing to our ability to compete in the high technology global marketplace.

Table 1. National Critical Technologies

MATERIALS

- Materials synthesis and processing
- Electronic and photonic materials
- Ceramics
- Composites
- High-performance metals and alloys

MANUFACTURING

- Flexible computer integrated manufacturing
- Intelligent processing equipment
- Micro- and nanofabrication
- Systems management technologies

INFORMATION AND COMMUNICATIONS

- Software
- Microelectronics and optoelectronics
- High-performance computing and networking
- High-definition imaging and displays
- Sensors and signal processing
- Data storage and peripherals
- Computer simulation and modeling

BIOTECHNOLOGY AND LIFE SCIENCES

- Applied molecular biology
- Medical technology

AERONAUTICS AND SURFACE TRANSPORTATION

- Aeronautics
- Surface transportation technologies

ENERGY AND ENVIRONMENT

- Energy technologies
- Pollution minimization, remediation, and waste management

Related Government and Private Sector Initiatives

In response to the Fiscal Year 1989 Defense Authorization Act, the Department of Defense (DoD) published its first ***Critical Technologies Plan***. This was revised in March 1990 and will be updated annually. Although the plan focuses exclusively on technologies that are essential to maintaining the qualitative superiority of U.S. weapon systems, many of these are "dual-use" technologies that provide significant benefits to the nation's economy. This effort now centers on developing integrated plans for achieving defense technology capabilities in priority areas. The plans will ensure that duplication is avoided and that critical technologies will receive appropriate emphasis within the DoD science and technology program.

The Department of Commerce (DOC) followed in the spring of 1990 with its report ***Emerging Technologies: A Survey of Technical and Economic Opportunities***. This report identified 12 emerging technologies which are expected to have the potential of contributing to the development of new or improved products by the year 2000. The report assessed the relative competitive positions of the United States, Japan, and the European Community with respect to the development and commercialization of these technologies.

Recently, several private sector organizations have conducted studies which examine key technologies for specific industries or sectors. The reports prepared by the Aerospace Industries Association and the Computer Systems Policy Project are noteworthy examples. The private sector Council on Competitiveness also engaged in a study of technology policy and priorities from the perspective of U.S. industry. The Council's report was released in March 1991.

With the central role that technology has assumed in our everyday lives, technology issues have also generated considerable interest among America's trading partners, and they too have identified "critical" technologies based on their perceived national needs. Japan's Science and Technology Agency publishes a biennial Technology Forecast Survey, and in 1990, the European Community released a list of key technologies which, in their view, merited strong Community resource commitment and support.

Although the scopes of the various "critical," "key," or "emerging" technology studies differ, there is extensive overlap among them. As has already been emphasized, identification of critical technologies is not the problem. The challenge is to develop and deploy them, swiftly and strategically.

DISCUSSION

The importance of technology deployment is emphasized in several ways in this report. First, five of the "critical" technologies identified on the list are process technologies, namely:

- Materials synthesis and processing
- Micro- and nanofabrication
- Intelligent processing equipment
- Flexible computer integrated manufacturing
- Systems management technologies.

The importance of product realization and manufacturing issues is also noted in the other 17 technology areas.

The prior work of other Federal government and private sector organizations that examined critical technologies was taken into account. The DoD and DOC reports were especially useful as source material because they addressed the issue from a Federal government perspective. The DoD focused on critical technologies for national security and the DOC focused on emerging technologies for commercial ends, thereby covering the same areas of emphasis as this report (see Table 2). However, the National Critical Technologies include surface transportation, energy, and environmental technologies, which were not addressed by either DoD or DOC. Although all three reports include materials and manufacturing technologies, the present report provides greater emphasis and more specific coverage of these technology areas which underlie and enable technology innovations across the entire economy.

Table 2. Comparison of National Critical Technologies with Department of Commerce Emerging Technologies and Department of Defense Critical Technologies

NATIONAL CRITICAL TECHNOLOGIES	COMMERCE EMERGING TECHNOLOGIES[1]	DEFENSE CRITICAL TECHNOLOGIES[2]
MATERIALS		
• Materials synthesis and processing	• Advanced materials	• Composite materials
• Electronic and photonic materials	• Advanced semiconductor devices • Superconductors	• Semiconductor materials and microelectronic circuits • Superconductors
• Ceramics • Composites • High-performance metals and alloys	} Advanced materials	} Composite materials
MANUFACTURING		
• Flexible computer integrated manufacturing	• Flexible computer integrated manufacturing	
• Intelligent processing equipment	• Artificial intelligence	• Machine intelligence and robotics
• Micro- and nanofabrication		
• Systems management technologies		
INFORMATION AND COMMUNICATIONS		
• Software	• High-performance computing	• Software producibility
• Microelectronics and optoelectronics	• Advanced semiconductor devices • Optoelectronics	• Semiconductor materials and microelectronic circuits • Photonics
• High-performance computing and networking	• High-performance computing	• Parallel computer architectures
• High-definition imaging and displays	• Digital imaging	• Data fusion
• Sensors and signal processing	• Sensor technology	• Data fusion • Signal processing • Passive sensors • Sensitive radars • Machine intelligence and robotics
• Data storage and peripherals	• High-density data storage	• Photonics
• Computer simulation and modeling	• High-performance computing	• Simulation and modeling • Computational fluid dynamics
BIOTECHNOLOGY AND LIFE SCIENCES		
• Applied molecular biology	• Biotechnology	• Biotechnology materials and processes
• Medical technology	• Medical devices and diagnostics	
AERONAUTICS AND SURFACE TRANSPORTATION		
• Aeronautics		• Air-breathing propulsion
• Surface transportation technologies		
ENERGY AND ENVIRONMENT		
• Energy technologies • Pollution minimization, remediation, and waste management		
		• No National Critical Technologies counterpart: High energy density materials, Hypervelocity projectiles, Pulsed power, Signature control, Weapon system environment.

[1] U.S. Department of Commerce, ***Emerging Technologies: A Survey of Technical and Economic Opportunities***, Spring 1990.
[2] U.S. Department of Defense, ***Critical Technologies Plan***, 15 March 1990.

Many of the National Critical Technologies support or enable other critical technologies. For example, continuing advances in computer software are necessary to support development of advanced capabilities in simulation and modeling, high-performance computing, and intelligent processing equipment. Technologies such as microelectronics and optoelectronics, simulation and modeling, and materials and manufacturing are essential to the continued development of virtually all other advanced technologies. In light of this interdependence, rank-ordering of the selected technologies was considered to be neither feasible nor desirable.

While the order in which the technologies are listed in this report does not reflect a prioritization among the technologies, it does acknowledge a difference between the categories of technologies selected. The first three categories, namely, Materials, Manufacturing, and Information and Communications, include technologies that form the basic "building blocks" for virtually all sectors of the economy. Biotechnology and Life Sciences, Aeronautics and Surface Transportation, and Energy and Environment are more akin to major areas for technology applications. However, the common denominator of all 22 technologies is the Panel's belief that they represent primarily technological issues, the solution of which is critical to future U.S. national security and/or economic well-being. The Panel's ground rules led it to exclude from consideration important technological issues and challenges having insufficient direct impact on economic prosperity or national security, such as space exploration, and a number of issues where the Panel believed the primary challenges were not technical in nature.

Comparisons of the National Critical Technologies, the DOC Emerging Technologies, and the DoD Critical Technologies in Table 2 demonstrate the substantial degree of overlap that exists between those technologies essential for national security and those that contribute to economic competitiveness. Although a small number of highly defense-specific DoD Critical Technologies (e.g., signature control, pulsed power, and high energy density materials) are not included among the National Critical Technologies, most of the DoD technologies are "dual use" in nature, and potentially are as important for their nondefense applications as they are to DoD. Both future U.S. national security and economic well-being rely to a substantial extent on continuing efforts in universities, Federal laboratories, the private sector, and the government to capitalize on the technological promise and realize the benefits of these technologies.

Finally, the Panel recognizes the importance of science and mathematics education to the nation's ability to remain a world leader in technology and technology application. Our ability to reap the benefits of the National Critical Technologies will depend on the generation of a technically literate workforce that possesses the skills necessary to develop and master these and future technologies.

The following sections present brief profiles of the National Critical Technologies. Each profile describes the technology, highlights the reasons for its selection, and discusses its current status and emerging trends.

MATERIALS

- Materials Synthesis and Processing
- Electronic and Photonic Materials
- Ceramics
- Composites
- High–Performance Metals and Alloys

MATERIALS

The current "revolution" in the field of materials, involving the development of new and superior metals, nonmetals, and composites together with completely new ways of producing them, is beginning to permit design engineers to specify materials having properties that would have been unthinkable a decade ago. Increasingly, it is possible to produce materials having essentially the exact combination of properties (e.g., strength, light weight, temperature or corrosion resistance, etc.) desired. The consequences include:

- Lighter, more agile, and more "stealthy" aircraft structures
- Higher–performance aircraft engines (permitting greater speed and acceleration and/or improved fuel efficiency)
- Novel medical applications
- Advanced automobile body and propulsion system components
- Stronger, lighter, and more energy efficient construction materials.

Many recent developments in materials technology were driven by the challenging requirements of military and aerospace systems. However, performance–cost trade–offs are much more critical to the widespread commercial application of new materials. Consequently, the emphasis is on efficient synthesis and processing techniques that will permit the manufacture of sophisticated and complex materials, sometimes engineered literally an atomic layer at a time. Another trend is towards intrinsically clean processing, with a focus on near net shape production, minimizing machining and other process steps that produce waste or consume excess amounts of energy.

The Panel highlighted an array of materials synthesis and processing technologies as well as three advanced materials technologies — ceramics, composites, and high–performance metals and alloys — that have important trade–offs in a wide range of structural applications. The Panel also highlighted electronic and photonic materials, the fundamental enabling technology for virtually all information and communications technologies. The growth and impact of both electronics and photonics have always depended on the materials upon which they are based. Integration of electronic and photonic devices on a single circuit will lead to revolutionary new products.

MATERIALS SYNTHESIS AND PROCESSING

DESCRIPTION OF TECHNOLOGY

The synthesis and processing of materials are central to the translation of new research and designs into useful products, as well as the timely and efficient introduction of advanced materials into the marketplace. Synthesis is the development of new materials or novel techniques to produce familiar materials. Materials processing is the preparation, forming, and shaping of raw materials into finished objects. In practice, the distinction between synthesis and processing is blurred; it is often difficult to determine precisely where synthesis ends and processing begins. Synthesis and processing are best described as a continuous spectrum of activities involving the generation and aggregation of atoms or molecules into useful products.

Synthesis and processing encompass a broad range of techniques and technologies including rolling of sheet steel, pressing and sintering of ceramic powders, creation of artificially structured materials, thermomechanical processing of alloys, preparation of polymers by chemical reactions, coating of turbine blades for corrosion resistance, growth of gallium arsenide crystals, and laying-up of composite materials. Some of these technologies are new and have potentially revolutionary implications. Others are established techniques which require continual improvements to ensure the future competitiveness of U.S. industry.

Synthesis and processing research is opening new horizons in materials science. Increasingly, it is possible to tailor new materials -- atom by atom -- to achieve a desired set of properties. To harness the potential of these revolutionary advances in materials science, U.S. industry must strive to integrate material synthesis and product design in the fabrication of highly specialized materials for specific applications. The capability to formulate "designer materials" will be an important source of technological progress, as well as competitive advantage, in the coming years.

Synthesis

Synthesis underlies much of the progress in materials science and technology. Advances in synthesis yield new materials having novel or superior properties, or improvements in the properties of known materials. This field is an important source of discovery of new chemical and physical phenomena in solids, such as high temperature superconductivity. Three important areas in the field of synthesis are the development of artificially structured materials, ultrapure materials, and novel synthesis methods.

Artificially Structured Materials. The synthesis of artificially structured materials represents a potentially revolutionary development in materials science. These materials are fabricated one atomic layer at a time, requiring precise and sophisticated fabrication techniques. Through control of composition and distribution at the atomic scale, specific material properties and significant improvements in performance may be achieved. Artificially structured materials, therefore, represent a leading edge in the development of "designer materials."

Presently, thin films are the most widespread of artificially structured materials. They are fabricated by depositing a layer, sometimes only one or two atoms thick, on a substrate using such processes as molecular beam epitaxy, chemical vapor deposition, vacuum evaporation, sputter deposition, or chemical beam epitaxy.

Artificially structured semiconductors are essential to the development of high-speed microelectronic devices and circuits. Progress in this field will permit the integration of photonic materials with microelectronic circuitry to yield optoelectronic integrated circuits (OEICs). To date this field has focused largely on semiconductors, but this approach may also permit the development of novel combinations of metals, insulators, and polymers.

Ultrapure Materials. The synthesis of very pure materials is critical for microelectronics applications and the development of emerging structural materials. The production of extremely pure silicon is a prerequisite to the manufacture of high-performance microprocessors and integrated circuits. Development of extremely pure and flawless compound semiconductor crystals will be essential to the advent of optoelectronic devices. The preparation of high purity volatile precursors remains an important technical challenge in microelectronics. For structural materials, there is a growing appreciation of the role of carbon and oxygen impurities in limiting the strength and reliability of reinforcing fibers in polymer matrix composites (PMCs). Impurities can cause microscopic cracks in advanced ceramics, and often induce the characteristic brittleness of these materials. Advances in the ability to synthesize extremely pure ceramics could determine the ultimate success of these strategic high-temperature materials.

New Synthesis Methods. There is an on-going need to develop superior new approaches to synthesis based on understanding of the relationship between structure, composition, and properties, and hence performance. Research opportunities exist for the development of novel lightweight, high-temperature structural materials for the aerospace and transportation industries; semiconductor and packaging materials for high density microelectronic circuits; magnetic materials for massive information storage; high-temperature superconductors exhibiting toughness and workability; and non-corroding biomaterials for medical implants.

Processing

Material processing traditionally has relied on a combination of mechanical and thermal treatments -- such as melting, casting, forging, rolling, pressing, and machining -- to achieve the desired properties and shape. Increasing demands for more complex materials with superior properties have stimulated the development of a range of innovative processing techniques that are beginning to complement or supplant the traditional approaches. Near net shape processing, rapid solidification, electron beam processing, and laser hardening are examples of some recently introduced techniques.

Near Net Shape Processing. In conventional processing, materials are first synthesized in bulk, and then machined or formed into the shape of the final product. The transformation from bulk form to final shape is often expensive and time-consuming, and involves discarding significant amounts of raw material. Moreover, this approach requires that materials not only possess the properties desired in the final product, but also be suitable for later stage processing. This constrains the use of a number of advanced materials. For example, the processing of ceramics by traditional means is largely limited to simple shapes, since their hardness and brittleness makes finishing operations difficult and expensive.

The development of near net shape processing techniques represents an important step towards realizing the full potential of many advanced materials. In effect, these techniques integrate the synthesis and processing steps to produce a mass whose shape closely approaches the dimensions of the final product. By eliminating several intermediate operations and reducing scrap, near net shape processing can significantly reduce fabrication costs.

Some near net shape techniques are well established, while others are still in development. Hot isostatic pressing (HIP) is now extensively used to produce a dense, near net shape product through the simultaneous application of high pressure and temperature. It is widely employed in the processing of superalloys and advanced ceramics.

Metal injection molding is another novel process with the potential for supplanting traditional metalworking techniques. In this method, metal in fine powder form is introduced into a medium of wax or thermoplastic, injected into a mold, and heated. The final product is then "HIPped" to increase its density. Metal injection molding makes possible the production of metallic parts of complex shape without machining.

Superplastic forming can also be used to process metals and other materials into intricate shapes. This technique involves slow deformation of the material at a relatively high temperature. Under these conditions and given a sufficiently fine microstructure, many materials exhibit extensive ductility. Thus, they can be readily formed or pressed into complex shapes. The component is then heat treated, rapidly cooled, and aged to produce a strong and stable structure. While presently used primarily with titanium alloys, superplastic forming has also been demonstrated with ceramics, intermetallics, and high carbon steel.

Rapid Solidification Processing. In conventional metal casting processes, alloying elements sometimes "segregate" at grain boundaries. Consequently, the resultant microstructure of the metal or alloy is not uniform. This degrades strength and performance. In rapid solidification processing (RSP), molten metal is cooled at high rates -- up to 1,000,000° C per second -- to achieve a uniform and fine-grained microstructure, thereby yielding stronger and more reliably performing alloys. RSP can also be used to synthesize alloys that cannot be achieved by conventional techniques. One such RSP approach is splat cooling, in which droplets of molten metal are sprayed onto a cooled surface. Another is gas atomization, in which droplets are cooled by an inert gas. Since RSP products must have a large surface-to-volume ratio to achieve the necessary cooling rates, this process is best suited for the production of powder, flakes, or ribbon. RSP is beginning to be used to produce high temperature materials for aerospace applications.

Electron Beam Processing. High-performance metals must be extremely "clean" — free from contaminating particles — since such particles can induce microscopic cracks that initiate subsequent catastrophic failure. The electron beam process is thus employed in the production of metals and alloys intended for critical structural applications. The electron beam strikes and melts the metal, releasing unwanted gas molecules and other impurities into the vacuum environment. The molten metal then drips down onto a cold hearth. This process is used primarily in producing titanium and nickel-based superalloys for jet turbine components.

Laser Hardening. Industrial lasers are widely used in the crystallographic transformation hardening of selected surface areas of metal parts. In this process, the laser beam quickly heats the surface to some temperature below its melting point but within the phase transformation range for this specific alloy. When the beam is turned off, rapid cooling occurs. The result is a more uniform and finer surface microstructure which enhances the strength and hardness of the part. An important advantage of this technique is that laser hardening affects only those areas that require additional hardening, leaving unchanged the bulk of the metal, which might become brittle if exposed to similar treatment. Laser hardening is used in the production of medical implants, high-performance bearings, and some extrusion dies.

Others. While the techniques described above represent some of the most promising developments in materials processing, many other methods also have important potential. Such techniques include diffusion bonding, exothermic reaction synthesis, dynamic compaction, and mechanical alloying. Reaction-injection molding and resin-transfer molding are beginning to find application for polymer matrix composites.

Optimization of these new processing technologies and of existing processing methodologies is required to achieve higher quality and lower unit cost. Advances on three fronts are needed here: process modeling to characterize critical variables; in-situ sensors to measure these parameters during processing; and advanced control concepts using expert systems and neural networks. Integration of these three concepts into "intelligent processing systems" has been demonstrated in processing several advanced materials (e.g., polymer matrix composites, gallium arsenide, and titanium aluminide) and will see increasing application in conventional and advanced materials during the next decade.

REASONS FOR SELECTION

The synthesis of novel materials is fundamental to technological progress in many key industrial sectors, including microelectronics, aerospace, transportation, and energy. The current challenge is the economical and efficient production of reliable products with predictably superior properties.

STATUS AND INTERNATIONAL TRENDS

The United States needs to accelerate the development of superior synthesis and processing technology, not only for the newer materials, but for commodity materials as well. This field of study has not been as popular in the United States as in Europe and Japan, and greater emphasis will be required both in terms of education and application to maintain national competitiveness. The problem is that U.S. scientists traditionally have concentrated their studies on the properties of novel materials rather than on their synthesis, which has often been left to foreign laboratories. This approach is unsatisfactory, as foreign laboratories continue to develop the capabilities to study the behavior of novel materials, as well as to create and synthesize them. The decline of basic research in U.S. industry and the growing focus of industrial laboratories on short-term product development have exacerbated U.S. shortcomings in materials synthesis.

The outlook in materials processing is similarly clouded, particularly in high volume processes critical for commercial success. Many experts believe that shortcomings in materials processing have contributed significantly to the competitive problems of the U.S. microelectronics industry. In contrast, the Japanese in particular have developed a formidable capability in manufacturing and related materials processing technologies in a diverse set of industries. Other nations, such as South Korea and Brazil, are emulating the Japanese emphasis on process technologies. However, the United States maintains a leading position in the development and incorporation of advanced processing techniques for aerospace and other high-performance applications.

ELECTRONIC AND PHOTONIC MATERIALS

[Semiconductor, Superconductor]

DESCRIPTION OF TECHNOLOGY

Advances in electronic and photonic materials will set the pace of technological progress in communications, image processing, and information processing -- key sectors for both the civilian economy and national security. The primary challenge is to develop materials that effectively integrate electronics and photonics to achieve dramatic improvements in systems performance, reliability, and cost.

Electronic Materials

Semiconductors are the primary materials for most electronic devices and integrated circuits. While other materials like polymers, ceramics, metals, and composites also play important roles as insulators or conductors, semiconductors can be made into transistors -- the fundamental devices of today's information society. Although semiconductors normally are poor conductors of electricity, they can become highly conductive when "doped" with certain impurities. The controlled flow of electric current through doped regions of the semiconductor is fundamental to the functioning of microelectronic devices.

Silicon has been the dominant material in the microelectronics revolution. Its many advantages include abundance, low cost, and high mechanical strength. Moreover, silicon crystals are easily grown and fashioned into wafers yielding millions of microelectronic devices. Most importantly, silicon forms a high-quality, native oxide which can be obtained by heating the material in the presence of oxygen. This oxide provides an insulating layer that is an extremely important component of field effect transistors (FETs), fundamental devices in silicon electronics. In slightly modified form, this oxide serves other important functions, such as isolating devices from the substrate and as a protective coating for integrated circuit components. The existence of such a high-quality, native oxide — along with highly developed processing techniques — has helped make possible the mass production of high-performance, low-cost, and reliable silicon-based microelectronic devices and integrated circuits.

Despite the success of silicon, the desire for increased performance has spurred efforts to develop improved semiconductors for microelectronic applications. The most promising current alternative is gallium arsenide (GaAs), a compound semiconductor. Electrons can move through GaAs crystals with greater speed than in silicon while generating less heat, thereby making possible the development of faster microelectronic devices with lower cooling requirements. GaAs is also more resistant to nuclear radiation -- a key advantage in many military and space applications. Already, GaAs integrated circuits have been employed in the most recent generation of ultra-fast supercomputers.

Unfortunately, fabrication problems and high costs have constrained the widespread use of GaAs-based devices. Unlike silicon, gallium and arsenic are relatively scarce elements. GaAs crystals are difficult to grow, and are much more expensive than silicon crystals. Another serious shortcoming of GaAs is its lack of a high-quality, native insulating oxide. The absence of such a protective, electrically insulating layer has complicated the manufacture of very large-scale integrated circuits. Researchers have had difficulty developing effective insulating layers for GaAs which can be easily mass produced, in part because of their incomplete understanding of how GaAs interacts with other materials. While GaAs and related compound semiconductor materials offer potentially important gains in performance, materials problems currently limit the use of GaAs-based devices and integrated circuits to highly specialized applications.

Photonic Materials

Photonic materials include those materials that generate, detect, or transmit coherent light. To date, photonic materials have had their greatest commercial impact in the telecommunications sector, where fiber optic cable is rapidly supplanting copper wire. Since this application is addressed in ***High–Performance Computing and Networking***, the following discussion focuses on the use of photonic materials as generators and detectors of light.

Lasers are devices that generate coherent light. While a variety of lasers are used in a range of photonic devices, semiconductor lasers are most compatible with microelectronic devices and therefore are of primary interest here. The first semiconductor lasers were made of GaAs and aluminum gallium arsenide. A variety of innovative lasers have been or are being developed, based on indium gallium arsenide, indium gallium arsenide phosphide, and other compound semiconductor materials. Semiconductor lasers have important commercial applications as the source of light for fiber optics telecommunications, compact disc players, and display systems.

In contrast, detector materials convert light into electric current. While these devices have the opposite function of lasers, they operate on similar physical principles. Light stimulates the semiconductor electrons, which are excited into their conductive state. The detector can therefore translate lightwaves into electrical signals, which then are processed into information by microelectronic devices. Most detectors are made of semiconductors like silicon, GaAs, lead selenide, and mercury cadmium telluride. Such detectors are integral components in optical communications, laser guidance, thermal imaging, bar code readers, robotics, copy machines, video cameras, and other commercial and military systems. Advanced detector materials, such as platinum silicide and indium gallium arsenide, are being developed for specialized, high–performance applications.

REASONS FOR SELECTION

Innovative electronic and photonic materials have the potential to profoundly benefit the national security and economic competitiveness of the United States. The development of GaAs–based integrated circuits is a pacing technology in the development of the next generation of high–performance supercomputers, and is central to DoD efforts to develop more capable, nuclear radiation–resistant defense systems. Photonic technology also has been fundamental to the development of key defense systems for communications, detection, and guidance. Semiconductor lasers and detectors are transforming telecommunications, consumer electronics, and image processing.

Despite such important innovations, the truly revolutionary potential of photonics and electronics lies in the marriage of the two fields. Electronic circuits are nearing their theoretical performance limits in information processing. Electrons moving through semiconductor materials generate heat and electromagnetic interference. These factors limit how closely microelectronic devices can be packed in a single integrated circuit. Moreover, the electrical connections that link microelectronic devices, circuits, components, and systems can carry only limited quantities of information. As a result, the speed with which a microprocessor can manipulate information is greater than the rate at which that information can be sent to other components or the end user.

Photonics represents a promising alternative approach for overcoming the inherent limitations of conventional electronics. Photonic materials can transmit much greater quantities of information than conventional wire connectors, and do it without generating heat or electromagnetic interference.

Current technology allows a relatively rudimentary level of optoelectronic integration in the form of fiber optic connections between otherwise independent receivers and processors (e.g. fiber optics telecommunications). The next step will be photonic links between microprocessors (or between microprocessors and other components such as data storage units), followed by optical interconnects between individual circuits. The optoelectronic integrated circuit (OEIC) -- which would link microscopic photonic and electronic devices (e.g. detectors, lasers, transistors) in a single monolithic circuit -- represents the most advanced expression of optoelectronic integration. When developed to a level that is comparable to current microelectronic circuitry, OEICs are likely to provide major advances in information processing capabilities.

Materials compatibility represents an important obstacle to increased levels of optoelectronic integration. Photonic materials, GaAs or related compound semiconductors, are not fully compatible with silicon, the primary material of microelectronics. (Silicon is not an effective photonic material, as it does not emit coherent light and cannot detect light emitted by many key lasers.) Since GaAs is both an efficient photonic material and has great promise in microelectronic applications, this compound semiconductor has outstanding potential for optoelectronic integration — if fabrication difficulties and other related material problems can be overcome. Alternative approaches include the use of a thin GaAs layer on a silicon substrate, and the development of silicon superlattice crystals with improved optoelectronic properties.

In theory, photonics has the potential to eventually supplant not only the electronic connections that link microelectronic devices, but also the semiconductor switches that perform the logic functions in microprocessors. In principle, photonic processors could manipulate information at significantly greater speeds than existing semiconductors. Despite this potential, there is a strong consensus that without dramatic technical breakthroughs, optical data processing may be several decades away because of the practical difficulties of fabricating and integrating all of the requisite components on a microscopic scale.

In the long term, the use of superconducting materials may lead to major improvements in speed and reduced power dissipation of electronic devices and components. For example, electronic switches can be fabricated using Josephson junction technology that are many times faster than conventional semiconductor switches. There are difficult materials problems to be overcome, however, before superconducting electronics becomes commercially viable. Because of this, the technology appears to be in a much earlier stage of development than optoelectronics. Furthermore, the need for refrigeration may restrict the technology to niche markets. In order to foster applications, the U.S. government maintains an extensive research and development program in superconductivity that focuses on materials studies, superconducting wire, and electronics.

STATUS AND INTERNATIONAL TRENDS

The United States faces a severe competitive challenge from Japan in the development of advanced electronic and photonic materials, as well as in optoelectronic integration. Japanese capabilities in the fabrication of high-quality, low-cost electronic materials have been an important factor in the rapid growth in the Japanese share of the microelectronics market. The Japanese private sector and government are involved in several initiatives to develop GaAs technology for commercial use.

U.S. firms are about even with their European and Japanese counterparts in the technology needed to produce silicon wafers used in the production of semiconductor devices. However, the market share of U.S.-owned companies in the silicon wafer market fell from nearly 60 percent in 1985 to under 10 percent in 1989, partly as the result of the foreign acquisition of U.S.-based suppliers. Given the increased foreign control of this production base, the United States will have difficulty maintaining technological leadership in this critical technological area. Moreover, European and Japanese firms already hold a signficant lead over the United States in the development of GaAs-based microelectronic devices and integrated circuits, not only in terms of market share but also in the superior quality of foreign-made GaAs wafers.

The Japanese position is also very strong in photonic materials and devices. Although the semiconductor laser was first developed in the United States, Japan is now the world leader in the production of both low cost lasers employed in compact disc players as well as high-performance devices used in long-distance fiber optic communication systems. Fiber optics is the only photonics component in which the United States has maintained its competitiveness.

The Japanese advantage in electronic and photonic materials could be a decisive edge in the development of more fully integrated optoelectronic circuitry. Integration is a primary thrust of the Optoelectronics Joint Research Laboratory, a collaborative program involving the Japanese government and several industrial organizations. Such efforts, should they be successful, would have a direct impact on the health of the U.S. micro-electronics and computer industries, and could jeopardize the competitiveness of the many sectors dependent upon information processing.

CERAMICS

DESCRIPTION OF TECHNOLOGY

Ceramics have been used by man for centuries in the form of bricks, tile, and glass. In recent years, however, the development of sophisticated processing methods and improved synthetic procedures has resulted in a new generation of advanced ceramics. These exhibit properties that offer potential benefits in several industrial sectors.

The new or "advanced" ceramics are made from pure, inorganic, nonmetallic powders of highly uniform size and shape. These powders are processed at high temperatures, frequently supplemented by high pressure, to form dense, hard structures. In comparison with traditional metals, advanced ceramics generally have high strength, low relative weight, and excellent high-temperature and corrosion resistance. These characteristics -- particularly their ability to withstand extreme operating temperatures -- make advanced ceramics candidates for structural applications in advanced propulsion systems and high-performance applications.

Brittleness and poor reproducibility have been the primary limiting factors in the use of advanced ceramics. When exposed to stress, microscopic imperfections in the material can develop into cracks that can result in catastrophic failure. In recent years, however, researchers have developed several useful approaches to improving the toughness and reliability of ceramics. One promising approach is to reinforce the ceramic matrix with high-strength fibers, whiskers, or particles. These composite materials are known as ceramic matrix composites (CMCs). In CMCs, the reinforcement inhibits microscopic flaws in the matrix material from developing into full fledged cracks. Continuous fiber CMCs exhibit superior toughness and are favored for most high-performance applications, particularly in aerospace. To realize the full potential of CMCs, further progress is needed in improving the reliability of the matrix/reinforcement interface and in developing more cost-effective manufacturing techniques.

An alternative approach involves greater use of ceramic coatings. For some applications, coatings confer many of the advantages of the monolithic ceramics, with fewer drawbacks. For example, ceramic coatings can significantly improve the high-temperature capability and wear resistance of a superalloy component. A component coated with a thin ceramic layer will not share the tendency of monolithic ceramics toward brittle fracture. Moreover, the application of ceramic coatings is less expensive and complex than the fabrication of monolithic ceramic structures. Ceramic coatings are used extensively in high-performance aerospace bearings and turbine components, as well as industrial cutting tools. As in the case of monolithic structures, there is a need for improved toughness of ceramic coatings.

Ceramic materials are generally more expensive than competing metals or alloys because of the complexity of current fabrication methods, the high cost of ceramic powders, and the difficulty of machining to final shape. "Near net shape" processing has important potential to reduce the costs of advanced ceramics. Such methods permit the fabrication of a part in dimensions that are close to the desired final shape, thereby reducing scrap and costly, time-consuming machining. Hot isostatic pressing (HIP) is a near net shape technique that is being used for some advanced ceramic applications. By simultaneously applying pressure and heat to a mold containing ceramic powder, HIP technology can produce a ceramic structure that closely approximates the shape of the final component. The development of thermoplastic ceramics which can be pressed, cast, or molded when heated to a certain temperature, may represent another promising approach. Further refinements in near net shape processing methods, including even superplasticity, are key to reducing the costs of advanced ceramic products and components. (See ***Materials Synthesis and Processing***.)

REASONS FOR SELECTION

High-performance ceramics are a key enabling technology for high-temperature applications such as advanced engines, where potential advantages include increased performance and fuel efficiency due to higher combustion temperatures, more compact and lighter designs, and the reduction or elimination of the cooling system. Ceramics are also excellent materials for applications which require extreme wear or corrosion resistance. In general, ceramics are likely to make their strongest impact in those applications where performance is paramount. Cost considerations are likely to preclude the widespread acceptance of advanced ceramics in more cost-sensitive applications, at least until unit costs are reduced as the result of the development of an extensive ceramics manufacturing base and/or more efficient processing methods. The following discussion assesses the potential impact of these materials on specific sectors, including military/aerospace, surface transportation, manufacturing, and electronics.

Military/Aerospace

Advanced aerospace designs require dramatic improvements in propulsion capabilities to achieve desired levels of performance. Increasing combustion temperature is critical to achieving the needed improvement in thrust-to-weight ratios. Ceramics have the potential to withstand operating temperatures over 1600°C, far surpassing the maximum temperature capabilities of superalloys currently employed in high-performance turbines. Ceramics are also significantly lighter than superalloys. According to some estimates, all-ceramic turbines could provide as much as 40 percent improvements in power over current high-performance aircraft engines, with significant fuel savings.

In light of these potential benefits, efforts are underway to develop ceramic components for turbine hot sections in the next generation of high-performance military aircraft. While such applications require continued improvements in the toughness and reliability of ceramics, one aircraft manufacturer estimates that these materials will account for approximately 30 percent of the weight of turbine engines in high-performance military aircraft by the year 2000. Ceramic-based turbine engines for missiles, drones, and other short-life applications are in the final stages of development. Ceramic components will also be used extensively in the propulsion systems of advanced subsonic and hypersonic civil transport aircraft.

In addition to hot section components of advanced turbine engines, ceramics have other important applications for military and aerospace systems. Space shuttle tiles are made from a highly specialized ceramic material, and ceramics are being considered for high-temperature aerodynamic surfaces and secondary structures for future hypersonic vehicles, where operating temperatures are likely to exceed the capabilities of current metallic alloys. Because of their exceptional hardness, ceramics are used for armor in military ground vehicles and are increasingly prominent in high-performance aerospace bearings.

Surface Transportation

Ceramics are also having a growing impact on the development of advanced automotive engines. As with aerospace turbines, the use of ceramic components in automotive engine hot sections results in improved performance and fuel efficiency. Ceramic parts are being developed or used in a variety of high-temperature engine applications, including turbocharger rotors, pistons, liners, valves, and seals for water pumps. Although cost considerations currently limit the rate of introduction of ceramic components in the price-sensitive automobile market, ceramics nevertheless will play an increasing role in future automotive engine designs.

Manufacturing

Ceramics have demonstrated important capability in cutting tools, especially in competition with tungsten carbide-cobalt cermets as inserts for metal turning and milling operations. Ceramics also have significant potential for wear parts such as seals, valves, nozzles, wear pads, grinding wheels, and liners. Heat exchangers made of advanced ceramics have the potential to greatly improve the efficiency of industrial furnaces.

Electronics

The most widespread current application of advanced ceramics is in semiconductor electronics. Ceramics are used in integrated circuit packaging, capacitors, and, to a lesser extent, resistors. Important future markets for advanced ceramics potentially include ceramic sensors, integrated optic circuits, and semiconductors.

Other Applications

Bioceramics, or ceramics for medical applications such as dental or orthopedic implants, represent a major market opportunity for ceramic materials. The high-temperature capability of advanced ceramics could also enhance the performance of processing equipment in the chemical, petrochemical, and petroleum industries.

STATUS AND INTERNATIONAL TRENDS

The United States enjoys world leadership in ceramics research and development. The United States leads in the development and manufacture of high-performance CMCs, partly as a result of Government and industry's continuing commitment to aerospace R&D. However, U.S. industry has been relatively slow to incorporate advanced ceramics into non-aerospace applications. Moreover, U.S. industry is largely dependent upon European and Japanese firms for the supply of high-grade ceramic powders and fiber reinforcements.

Japan is superior to the United States in the processing of monolithic ceramics for non-aerospace commercial applications. Japanese firms dominate the market in ceramic packaging for microelectronic devices, and have established a clear lead over their U.S. counterparts in the introduction of ceramic components in automobile engines. Japanese automobile companies are working closely with the large, integrated Japanese materials firms to resolve the technical obstacles to the more extensive use of ceramic materials in automobile engines. One Japanese automaker has developed an all-ceramic diesel engine prototype which functions without a cooling system. In order to gain additional manufacturing experience, Japanese firms have incorporated ceramic materials in scissors and other consumer products.

There is concern that the Japanese may attempt to exploit their advantage in ceramics processing and "leapfrog" U.S. aircraft engine manufacturers. However, current Japanese capabilities in high-performance CMCs are relatively limited. France has demonstrated a strong commitment to develop high-temperature CMCs in support of its ambitious aerospace program. Germany is focusing its R&D on unreinforced ceramics in an attempt to fully understand these new materials before undertaking the development of CMCs. Sweden's strength in hot isostatic pressing techniques contributes to its significant ceramics processing capability.

COMPOSITES

DESCRIPTION OF TECHNOLOGY

Composites are hybrid materials consisting of reinforcing fibers or particles embedded in a matrix. The matrix and the reinforcements work together to yield a material with properties that are collectively more useful than those of the individual elements. While early composites such as plywood and fiberglass have long been in widespread commercial use, recent advances in materials science have resulted in high-performance composites which are far superior to traditional metals and alloys.

High-performance composites generally are categorized according to the matrix material. Such categories include polymer matrix composites (PMCs), ceramic matrix composites (CMCs), and metal matrix composites (MMCs). Carbon-carbon composites (C/C) constitute a specialized category that utilizes a carbon-based matrix reinforced with carbon fiber. Each category of advanced composites has distinctive properties and applications. PMCs are the most mature of the advanced composite technologies and, unlike other high-performance composites, already are in widespread use in both military and commercial applications. In contrast, CMCs, MMCs, and C/C composites are emerging technologies that currently are limited to a few highly specialized applications, mostly in military aerospace and space structures.

Reinforcing fibers are made from a variety of materials, including carbon, high-strength liquid crystalline polymers, silicon carbide, or specialty glass. They may employ continuous fibers, short fibers or "whiskers," or particles. Continuous fiber composites provide superior stiffness and strength in the direction of reinforcement. These composites exhibit increased performance but are expensive and difficult to fabricate. In contrast, whisker and particle composites are inexpensive and are relatively easy to produce but are suitable only for less demanding applications.

Polymer Matrix Composites

PMCs are lighter, stronger, and stiffer than traditional alloys and metals. However, these composites can tolerate only moderate service temperatures. While this shortcoming rules out their use in hot sections of jet engines, PMCs are ideal for aerodynamic surfaces, as well as automobile structures and other applications in which weight and strength are critical to performance and efficiency. PMCs also offer unprecedented design flexibility, since they can be tailored to each specific application through the careful selection of materials and arrangement of the reinforcing fibers.

High-performance PMCs are considerably more expensive than competing metals as a result of their complex, time-consuming fabrication processes. Thermosetting epoxy (a glue-like polymer) is the matrix material used for most current high-performance applications. Thermoset processing is complex, time-consuming, and expensive. Hand or automated lay-up of many layers of fiber, tapes, or broad goods is normally required, followed by a lengthy autoclave curing process, to achieve the desired strength and stiffness. Cycle times, which are a primary cost driver, often are measured in hours. As a result, these composites are employed largely in applications where performance is more important than price, such as military aircraft, space, and sports equipment. Advanced PMCs have caught on more slowly in industries that are highly cost competitive.

The implementation of high-volume, low-cost production methods is therefore critical to unlocking the commercial potential of PMCs. Thermoplastic resins are one promising technology for reducing costs and automating the fabrication process. Unlike thermosets, thermoplastic materials can be reshaped when exposed to certain temperatures. As a result, these composites can be reformed from bulk material into desired final shapes, thereby greatly simplifying processing. Moreover, these materials do not require autoclave curing and, consequently, have dramatically shorter cycle times than thermosets. Thermoplastics are therefore well-suited for forming operations like stamping and injection molding — mass production techniques which could greatly improve the affordability of PMCs. However, current thermoplastics have lower thermal strength and corrosion resistance than thermosets. These shortcomings must be overcome before thermoplastics can replace thermosets in high-performance applications.

In the coming decades, the use of PMCs in high-performance military aircraft will grow. Already, composites account for 26 percent of the weight of the AV-8B Harrier jump jet. For the Advanced Tactical Fighter (ATF), this figure is likely to rise to 40 percent. The use of PMCs in such applications results in average weight savings over conventional materials of 20-30 percent. Because of their tailorability and stiffness, PMCs also permit the development of advanced designs with smaller radar cross sections. PMCs have important potential in other military applications, including aerodynamic surfaces of helicopters and missiles, and the structures of armored vehicles.

Proficiency in producing and using PMCs will also be key to improving performance and reducing life cycle costs of commercial aircraft. While PMCs account for only three percent of the weight of the Boeing 757, some experts believe that the use of PMCs in commercial aircraft could rise to 65 percent by the year 2000. One U.S. firm recently began full-scale production of a small business aircraft with an all-PMC airframe. Airbus, the European consortium, is making extensive use of PMCs for primary airframe structures in its transport aircraft. (However, it is important to note that recent developments in Al-Li alloys, for which strengths of > 100 kpsi are now being obtained and which can retain strengths of about 70 kpsi up to 250°C, imply that aluminum alloys will remain a strong contender for aerospace applications for the foreseeable future. See ***High-Performance Metals and Alloys***.)

PMCs already are having an impact on the automobile industry. Relatively inexpensive composites, such as fiberglass, have been used in several automobile models for exterior surfaces. With further improvement in stamping and other processing techniques, low-cost PMCs may increasingly replace sheet metal in automobile manufacturing. U.S. automobile manufacturers also are developing all-PMC frames for possible introduction in the mid-1990s. Such applications would greatly simplify assembly by reducing the number of body parts, and provide improved fuel efficiency, ride quality, and corrosion resistance.

High-performance PMCs also have important potential for civil engineering applications, and are being tested for use in bridge and highway support structures. The development of low-cost PMCs may be key to the development of the manufactured housing industry. Finally, PMCs are used extensively in the sporting goods sectors in the production of tennis rackets, golf clubs, skis, and other sporting equipment.

Other Composites

Although less mature than PMCs, other high-performance composites are finding increasing use in military and commercial applications. C/C composites, which can tolerate higher operating temperatures than any other known composite, are utilized in rocket nozzles and reentry vehicle components. These materials have strong potential for high-temperature structural applications in hypersonic airciaft, space vehicles, and advanced propulsion systems. However, the development of C/C composites must surmount serious technical obstacles which have inhibited the widespread use of these materials. Major challenges include improving the oxidation resistance of C/C composites at high temperatures, as well as the reproducibility of C/C components.

As discussed in ***Ceramics***, advanced ceramics are considered instrumental to the development of advanced propulsion systems and other high-performance aircraft structures in light of their high-temperature capability and other superior properties. The primary constraint has been their tendency toward brittleness, which can result in catastrophic failure. CMCs offer a promising approach to improving the toughness of ceramics. In CMCs, the reinforcement fibers work to deflect microscopic cracks and prevent crack propagation.

CMCs could therefore be a primary means for improving the reliability of advanced ceramics and could help realize the considerable potential of these revolutionary materials. In addition to high performance aircraft turbines, CMCs are being developed for a variety of automobile engine components. (See ***Ceramics*** for further discussion of CMCs.)

MMCs exhibit dramatically superior characteristics in comparison to unreinforced metals, including lightweight strength, high specific stiffness, and high–temperature capability. As a result, MMCs are attractive for a number of relatively high–temperature applications in hypersonic aircraft, including leading edges and other hot sections of the airframe skin. MMCs are especially appropriate for space structures, where their high resistance to radiation provides a decisive advantage over PMCs. (In space, PMCs experience "out–gassing," or the release of water vapor and other compounds, which can collect on satellite instruments and degrade their effectiveness. MMCs are not susceptible to this phenomenon.) MMCs are beginning to find use in engine components and in a variety of vital high–temperature applications in the National Aero Space Plane and the proposed high speed commercial transport. Important constraints on the utilization of MMCs in these and other future applications include cost and the reliability of the matrix/reinforcement interface. Currently, MMCs can be found in Space Shuttle struts and the antenna boom for the Hubble Space Telescope. Japanese automakers have pioneered the use of reinforced aluminum in piston skirts. (See ***High–Performance Metals and Alloys*** for further discussion of MMCs.)

REASONS FOR SELECTION

According to the Aerospace Industries Association, worldwide PMC sales totalled almost $4 billion in 1989 alone. The Office of Technology Assessment estimates that worldwide annual sales of advanced composites will climb to $20 billion annually by the year 2000. As noted above, advanced composites are integral to high–performance military aircraft, other key defense systems, and the U.S. space program. These materials will play an increasingly prominent role in the civil air transport industry, and are a potential source of competitive advantage in the automobile industry.

STATUS AND INTERNATIONAL TRENDS

The United States has a strong across–the–board research and manufacturing base in advanced composites, and is both the world's largest producer and consumer of these materials. In general, U.S. capabilities are strongest in high–performance applications, but are somewhat less competitive in lower end composites that have potential for broad commercialization.

Much of the pioneering work on PMCs was conducted in the United States, and domestic suppliers are among the most important companies in the industry. Nevertheless, the position of other nations in PMC development and manufacturing has strengthened significantly. In recent years, European firms have acquired more than 20 U.S.–based suppliers, including many of the industry's most prominent companies. Moreover, the U.S. PMC industry has been oriented toward high–performance applications in space and military aviation. This focus is largely the result of extensive DoD and NASA sponsorship of R&D activity in PMCs and other composites. Consequently, supplier firms have focused relatively little attention on the commercial market.

In contrast, Japanese industry has sponsored the bulk of composites research in that country. Because of the lack of a mature Japanese aerospace industry, Japanese PMC firms have emphasized sporting goods and other commercial markets in order to acquire experience in composites design and manufacturing. Japanese firms are actively exploring the potential use of PMCs in civil engineering, construction, and other fields. By concentrating on processing and commercial applications, Japanese companies appear to be positioning themselves to take advantage of future non–aerospace markets. Japan is also the dominant supplier of carbon fiber.

Composites applications traditionally have consisted largely of simple replacements of metal parts with composite components of essentially identical shape. However, composites offer the potential for a revolutionary synthesis of materials science and product design with the advent of "designer materials." Innovative design and analysis methods must be developed in order to realize the full potential of these new materials. Detailed knowledge of the behavior and failure mechanisms of composite systems will provide the design data base for new product forms that fully utilize the unique properties that composites can provide over traditional metallic forms.

Advanced composites are a leading edge technology with profound implications for economic competitiveness and national security. To maintain world leadership in this critical technology, U.S. industry must continue to develop more cost effective processing methods and place greater emphasis on expanding commercial applications.

HIGH-PERFORMANCE METALS AND ALLOYS

[High Hardness, High Strength and Temperature Resistant; Includes Intermetallics]

DESCRIPTION OF TECHNOLOGY

High-performance metals (including alloys) exhibit superior strength, specific stiffness, heat resistance, and other mechanical and chemical properties in comparison to traditional structural metals such as steel. U.S. technological leadership in the development and processing of high-performance metals is an integral factor in maintaining the dominant position of the United States in the aerospace sector.

For decades, aluminum alloys and superalloys have been the primary high-performance metals used in aircraft (both civilian and military), space vehicles, and other aerospace systems. More recently, titanium alloys have come into significant use. These conventional high-performance metals have distinct properties which dictate their specific applications. Aluminum alloys, which are lighter than steel, have long been the primary material for airframes. Superalloys (based on nickel, cobalt, or iron) withstand relatively high temperatures and are employed widely in the hot section of aircraft engines. Titanium alloys were also developed for use in some engine components.

Although new processing methods, such as rapid solidification processing, continue to yield evolutionary improvements in the capabilities of these materials, conventional high performance metals clearly are approaching their technological limits. The U.S. aerospace industry cannot achieve the dramatic advances in performance required for advanced aerospace systems without the development of a new generation of lightweight, high-strength materials capable of withstanding extremely high operating temperatures. Along with ceramics and polymer matrix composites (PMCs), advanced high-performance metals are likely to play an important role as an enabling technology for advanced aircraft like the National Aero Space Plane, space-based strategic defense structures, and other military and space systems. Aluminum-lithium (Al-Li) alloys, metal matrix composites (MMCs), and intermetallics are among the most promising of these new metals.

Aluminum-Lithium Alloys

Al-Li alloys represent a promising approach to overcoming the technological limits of conventional alloys. A one percent lithium content reduces the weight of an aluminum alloy by three percent and increases its specific stiffness by six percent. Substitution of Al-Li alloys for conventional aluminum alloys could yield total weight savings of 10-20 percent throughout the airframe, thereby boosting aircraft performance and fuel efficiency. Recent advances have resulted in Al-Li alloys with much greater strength (up to 100 kpsi), useful strength retention at elevated temperatures (75 kpsi at 250°C), and improved welding characteristics.

To date, the use of Al-Li alloys in civilian and military aircraft has been constrained by their higher initial costs, as well as the lack of adequate experience in the design and use of these materials. A comprehensive data base on the characteristics and performance of Al-Li alloys is needed to overcome the reluctance of airframe manufacturers to promote the widespread structural application of a largely unfamiliar material. A firm commitment from the U.S. aircraft industry to use these alloys is also necessary in order to stimulate the needed investment in Al-Li processing -- the key to reducing fabrication costs. Despite such obstacles, Al-Li alloys are strong candidates for aerodynamic surfaces and other high-performance aerospace applications in which temperature requirements exceed the thermal capabilities of PMCs.

New aluminum alloys incorporating iron or other transition element alloying additions are also attracting attention for aerospace applications. These alloys, which are processed by rapid solidification techniques, also show promise for operating at higher temperatures than conventional aluminum alloys and, along with the new Al–Li alloys, could replace some titanium alloys in selected applications with significant weight and cost savings.

Metal Matrix Composites

MMCs consist of a reinforcement material embedded in a metal matrix. The reinforcement may be in the form of particles, whiskers, or continuous fibers or wires, and can be made from a variety of high strength materials -- usually ceramics such as silicon titanium carbide, titanium diboride, or alumina. MMCs exhibit dramatically superior characteristics in comparison to unreinforced metals and, like other composites, can be tailored for specific high–performance applications. For example, aluminum matrix composites demonstrate three to ten times greater strength than the monolithic metal, as well as superior stiffness and lower density. For these reasons, aluminum MMCs are attractive for a number of high–temperature aerospace applications in the hot section of aircraft turbines and rocket engines, as well as aerodynamic surfaces in hypersonic aircraft. They are also promising for space vehicles, where their resistance to radiation and "out–gassing" is an important advantage over PMCs. Some MMCs also have potential for non–aerospace commercial applications; for example, Japanese automakers have pioneered the use of aluminum matrix composites in automotive engine components such as piston skirts.

Despite these potential benefits, MMCs face several serious obstacles. Because the rates of thermal expansion of the matrix and reinforcement are usually different, the matrix/reinforcement bond has a tendency to fail after exposure to repeated temperature cycling, both during processing and in service. Similarly, reactions between the reinforcement and the matrix metal can degrade the interface unless these are carefully chosen to be thermodynamically stable. Most important, because of high raw materials costs and complex processing methods, MMCs are usually significantly more expensive than competing materials. The development of more cost–effective fabrication techniques is key to broader use of MMCs.

Intermetallic Alloys

Intermetallics are unconventional alloys which have great potential for high–temperature structural applications. Rapid solidification and other sophisticated processing techniques may be used to produce these alloys in which the atoms of the constituent metals are arranged into a highly ordered lattice or crystal structure. This superlattice structure results in high strength and, in some cases, high melting points. In fact, over some temperature ranges, certain intermetallics can even become stronger as temperature increases. Intermetallics are therefore a potential replacement for superalloys in the hot section of jet engines.

Titanium aluminides are among the most promising intermetallic candidates for aerospace applications because of their low density and high melting points. While less brittle than ceramics at low temperatures, the toughness of the titanium aluminides is lower than that of conventional metals, and therefore will likely be reinforced with ceramic particles or fibers. Such materials are being developed for use in the hot sections of advanced aircraft turbines and high–temperature aerodynamic surfaces. The complexity and cost of the resulting fabrication processes are the primary constraints to the widespread use of such intermetallics. The development of processes for the superplastic forming of intermetallics has significant potential to enhance current capabilities to fashion these materials into complex final shapes.

Nickel and iron aluminides are also being developed. While not capable of operating at the extremely high temperatures at which titanium aluminides can be used, they show great promise at lower temperatures, i.e., 800–1000°C. These intermetallics exhibit strong creep and oxidation resistance, and may challenge expensive materials such as stainless steels and nickel alloys for certain applications. In contrast to titanium aluminides, low temperature toughness is not a problem in these materials.

Intermetallics represent an emerging technology in materials science. While some components could be introduced on a limited scale in the mid-1990s, broader applications are not likely before the year 2000.

REASONS FOR SELECTION

Advanced high-performance metals and alloys are an integral enabling technology for future military aircraft and other defense systems; subsonic and supersonic civil transport aircraft; proposed space systems like the National Aero Space Plane (NASP); and space-based strategic defense structures. Preeminence in advanced metals and alloys is a prerequisite for continued U.S. world leadership in aerospace.

Advanced metals will compete with ceramics and PMCs in future aerospace applications. In general, high-performance metals offer higher temperature resistance, but lower strength and specific stiffness, than PMCs. They are tougher than ceramics, but tolerate lower operating temperatures. High performance metals and MMCs therefore occupy an intermediate position between PMCs and ceramics. Because of their high specific strength and stiffness, Al-Li alloys will compete with PMCs and MMCs to supersede conventional alloys in many airframe applications. Already, Al-Li alloys are in limited use in commercial aircraft as landing gear fittings and cabin floor beams. The C-17 military transport will include several Al-Li alloy components. This trend will accelerate as Al-Li alloys become cost competitive with conventional aluminum alloys by the mid-1990s.

MMCs with aluminum alloy matrices are under consideration for both selected airframe as well as engine applications. MMC technology is not as developed as Al-Li alloys, but is further refined than intermetallics. Where adopted, MMCs will compete with PMCs for many applications which now employ unreinforced metals. The relatively high costs of MMCs may limit their use. The key market for MMCs may be space vehicles, where their strong resistance to radiation and out-gassing is a key advantage over PMCs, and heat engines for aircraft, rockets, and power generation.

While Al-Li alloys and MMCs are already employed in limited applications, intermetallics represent a longer term, more revolutionary technological challenge. Intermetallic alloys, probably used in composite form, will compete with ceramics as the replacement material for superalloys in many high temperature applications, particularly in hot sections of advanced propulsion systems While intermetallics have a somewhat lower maximum service temperature, the reliability of ceramics in structural applications remains a concern.

To date, high-performance metals and alloys have had limited success in penetrating non-aerospace commercial markets, largely because of their higher costs. MMCs, however, are attractive for possible use as connecting rods and other reciprocating parts in automobile engines. A number of commercial applications are currently being pursued for nickel and iron aluminides.

STATUS AND INTERNATIONAL TRENDS

While the United States enjoys a strong position in advanced metals, Japan and major European countries can match U.S. technology in many areas. In the advanced areas of development — Al-Li alloys, MMCs, and intermetallics — the United States faces concerted overseas efforts to surpass its capabilities. Europe is building upon its aerospace industry expertise, while the Japanese challenge has its foundation in that country's large steel sector.

France, Germany, and the United Kingdom are engaged in vigorous research in a variety of key fields. France hopes to become the major supplier of Al-Li alloys for the next generation of Airbus aircraft. However, French suppliers still have some production problems that place French technology somewhat behind that of the United States. Germany has a major program in intermetallic compounds underway for possible applications in hypersonic aircraft and advanced aircraft engines. The United Kingdom is focusing its efforts on developing conventional titanium and aluminum alloys with higher temperature capabilities.

Japan is approaching U.S. capabilities in superalloy technology, and is becoming a major developer of intermetallics. Several Japanese steel companies are vigorously developing new metals and other materials in an effort to diversify from steel. Nippon Steel has world-class capabilities in developing titanium aluminides. The Japanese are also working on Al-Li technology, but remain substantially behind the world leaders in this field. Japanese firms are exploring non-aerospace applications for MMCs in order to develop future commercial markets and gain fabrication experience. Japan dominates the MMC market in the sporting goods sector, and Japanese automobile companies have pioneered the use of aluminum MMCs in engine components. In contrast, U.S. companies are highly oriented toward the military/aerospace markets and have not been as active in seeking novel commercial applications for high-performance metals.

MANUFACTURING

- Flexible Computer Integrated Manufacturing
- Intelligent Processing Equipment
- Micro- and Nanofabrication
- Systems Management Technologies

MANUFACTURING

Throughout its deliberations, the Panel placed heavy emphasis on the importance of manufacturing and process technologies. In this section of the report, four critical manufacturing process technologies are described:

- Intelligent processing equipment
- Flexible computer integrated manufacturing
- Micro– and nanofabrication
- Systems management technologies.

In addition, several other National Critical Technologies also highlight the importance of manufacturing and processing issues.

The manufacturing technologies identified by the Panel involve a combination of new technologies and changes in management and engineering practices. These technologies draw upon many other National Critical Technologies including sensors, controls, computer software and hardware, simulation and modeling, and new materials.

The current trend in manufacturing is a move toward more rapid product introduction, abbreviated product life cycles, increased flexibility, and integrated design–production–quality control. Companies which do not move in this direction will become increasingly noncompetitive. To achieve these streamlined operations, manufacturers must implement advanced manufacturing technologies and management practices throughout their operations.

Manufacturing technologies involve far more than simply factory automation. Ultimately, advanced manufacturing capabilities involve the integration of the entire enterprise, permitting rapid adjustment to changing conditions, maximum efficiency, optimum staffing and inventory, and improved product quality and affordability. Operations that will be affected include not only production, but also engineering design, purchasing, sales, and cost accounting. A systematic approach to the introduction of these technologies, along with changes in management practices, is essential to maximize their potential benefits. These new technologies cannot be grafted onto an existing organization. Instead, they imply a fundamental redesign in the approach to manufacturing.

U.S. economic competitors have tended to pursue advanced manufacturing processes and technologies, as well as the management systems that integrate these technologies, more aggressively than U.S. manufacturing companies. Continued competitiveness of U.S. manufacturing equipment producers will depend not only on their own actions, but on a "sea change" in management actions and investment practices at U.S. manufacturing enterprises.

FLEXIBLE COMPUTER INTEGRATED MANUFACTURING

DESCRIPTION OF TECHNOLOGY

Flexible computer integrated manufacturing (CIM) can reduce manufacturing lead time and costs and improve product quality. Through the use of computer technology, flexible CIM integrates product, process, and manufacturing management information into a single interactive network, greatly reducing the number of "transactions" necessary to produce the product. It affects all manufacturing functions including product engineering and design, process planning, production scheduling, subcontractor and vendor activities, part production and product assembly, inspection, and customer service. Flexible CIM now enables lower volume and more variety of product to be managed more like a continuous flow process than has ever been possible before. Costs and quality are comparable to the higher volume fixed automation systems. The key to successful application of a flexible CIM strategy is the ability to adjust rapidly to changes in engineering design, demand, or other product requirements. It helps ensure that the right product at the right price is on the market at the right time.

Whereas intelligent processing equipment (described in a separate section) focuses on the process/workstation level, flexible CIM addresses the management and process requirements at the factory level. Flexible CIM incorporates various levels of factory automation and information systems into a single coordinated system. At the lowest level, manufacturing tasks consist of individual steps and processes performed at individual workstations. A group of workstations, organized around a set of common tasks or functions, constitutes a factory cell. Collectively, these cells feed parts into factory centers, which may be composed of subassembly, assembly, and final assembly operations. The CIM system "oversees" all of the factory's operations, including its workstations, cells, and centers, and ensures that the factory can be responsive to both engineering and marketing inputs.

Flexible CIM integrates company-wide information systems, plant-wide planning and control systems, factory scheduling and center control systems, and individual workstations and cells. In theory, flexible CIM should be able to adjust rapidly to changes in production requirements, adapt to disruptions in other aspects of production, and manufacture parts in virtually any sequence. In general, the more advanced the system, the less direct supervision required, although optimal utilization of flexible CIM requires extensive planning and coordination. (See ***Systems Management Technologies***.)

The components of a flexible CIM system are very broad, and depend on the scope and nature of a particular enterprise's manufacturing task. Typical equipment used in a flexible CIM system includes:

- **Computer aided production, inspection and test equipment**, including machining and turning centers, composite tape laying machines, and coordinate measuring machines (programmable devices capable of automatic and precise measurements of parts)
- **Electronics assembly equipment**, consisting of programmable equipment to perform routine assembly functions and operations such as insertion of components into printed circuit boards. (Some current systems can carry out assemblies of 15,000 parts per hour.)
- **Process control equipment (PLCs -- programmable logic controllers)**, which are small, dedicated computers that control a variety of production processes, most often steps that must follow an established sequence (for example, heat treatment of metals, in which the sequence of steps and temperature must be controlled very precisely). Programmable controllers are finding uses in both continuous processes and discrete manufacturing tasks
- **Computer control of multiple, interrelated operations**, such as control of several racks of detail parts being processed simultaneously through various chemical tanks for degreasing, cleaning, rinsing, drying, and different surface treatments, in each case with different bath times and sequencing required. At a factory level, an application is the nightly

determination of the sequence and schedule of all factory operations for the following day.

Flexible CIM is the integration of these and other components. Some of the associated tools and technologies utilized to implement flexible CIM are discussed below.

Simulation Tools

Manufacturing simulation models contain data involving physical systems, control systems, management policies, vendor/supplier information, and exogenous influences on the enterprise and factory. Using interactive systems to simulate a task or set of subtasks, managers can design more effective manufacturing systems, increase utilization rates, streamline factory layouts, and simplify scheduling. Simulation and modeling enable project teams to design products in a manner that simplifies subsequent analytical tasks in the production phase. (See ***Simulation and Modeling*** for a more complete description.)

Computer Aided Design (CAD)

CAD already has an enormous impact on the manufacturing environment. Three generations of CAD systems are in use today. The first generation consists of two-dimensional, computerized drafting systems that streamline the process of drawing and editing plans or blueprints. The second generation enables three-dimensional designs, while the third generation allows operators to create solid object representations. The capabilities of CAD systems are continually developing. Three themes are evident in current CAD research: improving algorithms for representing objects; adding "intelligence" to CAD systems so that they can prevent design errors; and developing effective interoperability among CAD systems and manufacturing operations and managers.

Computer Aided Engineering (CAE)

Computers are being used to define, refine, and optimize the qualities of various products. CAE takes CAD techniques and benefits one step further, allowing interactive design and analysis to simulate performance. Although already used widely in manufacturing, these systems will become increasingly important as a means to reduce production and design cycles as well as manufacturing costs. They are important competitive and efficiency tools for product and tooling designers, production planners, and managers.

Group Technology (GT)

Group technology emphasizes identifying major similarities among items so that they can be grouped for more efficient production, by minimizing tooling changes or the reprogramming of manufacturing systems. Parts produced are classified according to their physical characteristics, qualities, or other criteria. GT enables planners to exploit similarities in parts and machining processes to improve factory and production efficiency. It is the basis for establishing workstations, cells, and factory centers.

Computer Aided Process Planning (CAPP)

This includes: establishing methodologies for determining processing sequences from part specifications, part characteristics, and/or assembly configurations; applying process models to determine economical operating conditions for each processing unit; and evaluating the impact of operating conditions within workstations and CIM systems on production rates and economics of the entire production sequence. Some systems allow the generation of three-dimensional models of a factory floor and systems to identify production and material flow bottlenecks. Utilizing CAPP would enable managers to determine the optimal production sequence and flow within a manufacturing system.

Two types of CAPP are currently available, variant and generative. Variant CAPP is the more common and simpler of the two. It relies on group technology to develop process plans for similar yet different parts by the same system, without extensive investments in reorganization of manufacturing processes. Generative CAPP, which is far more complex, is used to develop process plans based on multiple factors, including expert systems and artificial intelligence. Generative CAPP can also be used to optimize routing and production lead times, as well as to anticipate necessary changes in tooling.

Factory Scheduling Tools

These include computer-assisted material requirements planning (MRP) and manufacturing resource planning (MRP II). MRP is used to manage lead-times, in-process inventories, and other tasks. MRP II is a more advanced forecasting and scheduling tool.

REASONS FOR SELECTION

Although the U.S. economy is dependent on the service sector for its economic growth, both services and the economy continue to be driven by production capabilities. In addition, there is a strong linkage between manufacturing and the service sector: erosion of the manufacturing base will result in the loss of a significant portion of the service sector employment and trade that depend on it. Failure to maintain world-class manufacturing capabilities would compromise the nation's ability to compete in domestic and international markets, and would threaten our ability to continued economic growth and to obtain access to the full range of components and equipment required for a strong national defense.

Flexible CIM systems provide greater flexibility than traditional, dedicated processes, and are even superior to many fixed automated systems. As the introduction of new products accelerates, especially in high technology fields, the product life cycle is shortened and as little as 18 months may pass before a new generation of a product is introduced into the marketplace and the older product becomes obsolete. In addition, the size of production runs for advanced products is decreasing because of the shortened production life cycles, the growing demand for a large variety of parts and components, and increased "just in time" manufacturing and purchasing practices. To meet these competitive pressures, manufacturers must implement new manufacturing systems that are flexible enough to respond quickly to product and demand changes. Increasingly, economics will dictate that life cycles of manufacturing systems must span several product life cycles.

Although automation in machine tools and transfer-type machining systems was introduced initially for mass production, approximately 75 percent of total production in the mechanical industry is batch-type, or small lot production (production of 50 or fewer parts). This requires more flexibility and capability than is economical for traditional automated systems. The production of specialized parts has become more demanding in its own right, requiring the development of new technologies and systems simply to remain abreast of international competition.

Flexible CIM systems are also central to the affordability of complex and specialized weapon systems that are required for national defense. For example, it is widely recognized that strategic defense systems will only be affordable if widespread implementation of CIM concepts occurs at all levels of the defense industry.

In short, flexibility in manufacturing is essential to the efficient production of parts and entire products in today's rapidly changing marketplace. Flexible CIM is the most promising means of attaining such flexibility. Unfortunately, the use of these systems in U.S. industry is not yet widespread. In addition to its high cost, flexible CIM diverges from the manufacturing strategies that are commonly practiced in this country today, and requires alterations in most firms' operating philosophies. CIM affects not only physical aspects of production, but also such related areas as engineering design, purchasing, sales, and cost accounting. It is doubtful that even smaller firms that rely solely on domestic markets will be able to remain competitive without adopting flexible manufacturing strategies.

STATUS AND INTERNATIONAL TRENDS

Although industrial specialists believe that the number of flexible CIM systems in operation in the United States is double that of Japan, Japan nevertheless is well advanced in the field. In Japan, the field is more commonly referred to as Factory Automation (FA), an integrated approach to product design and manufacturing. Japan's work in the area is facilitated by the world's largest automated machine tool industry, world-class capabilities in information technology, and manufacturing and product development philosophies that are highly compatible with CIM. In fact, Japan's Ministry of International Trade and Industry has proposed an international collaborative research program to conduct joint research in promising automated information and manufacturing technologies, as well as to establish common international standards to facilitate their introduction and proliferation. Many of the systems that would fall under this program -- the Intelligent Manufacturing System Initiative -- go far beyond the technologies described here.

Many other management tools have been implemented in industry, with varying success. For example, a system for a major computer manufacturer assists managers with capacity planning and inventory management. The system can receive customer orders, generate manufacturing plans, and then use these plans to monitor implementation. A related CAPP process developed by a major U.S. research institution generates factory job schedules, selecting the sequence for each job to be performed, determining the starting and ending times, and assigning resources to each step. Still another system, developed jointly by U.S. industry and universities, helps control the manufacture and distribution of a firm's final products and develops assembly and testing plans based on customer orders and plant activity information. In addition, it can diagnose and suggest solutions to problems within the system.

INTELLIGENT PROCESSING EQUIPMENT

[Including Robotics, Sensors, and Controls]

The four technologies included in the "Manufacturing" category -- intelligent processing, flexible computer integrated manufacturing, micro- and nanofabrication, and systems management technologies -- are related, but have distinct roles in contributing to achievement of world-class manufacturing capabilities. Intelligent processing equipment is central to the successful implementation of advanced manufacturing strategies through flexible computer integrated manufacturing.

DESCRIPTION OF TECHNOLOGY

Intelligent processing equipment is the foundation on the shop floor upon which advanced manufacturing capabilities are built. It includes a broad range of computer-controlled equipment capable of carrying out a wide array of manufacturing processes such as machining, forming, welding, heat treating, painting, testing, inspecting, assembling, composite fabricating, and material handling. Flexibility, programmability, and controllability are inherent attributes of such computer-controlled equipment, but intelligent processing equipment carries these attributes to the next level of control through the use of sensory feedback. Furthermore, more than one process can now be integrated into an intelligent manufacturing workstation. The fundamental concept behind this critical technology is that the manufacturing process includes the ability to sense the desired characteristics or properties of a product and has enough local intelligence to control those properties.

Robots have been in the vanguard of this emerging technology. Most industrial robots are generic in concept and are not designed for a specific process. They must be coupled with other equipment and require additional information about the operational environment in order to perform the desired process. This requirement has necessitated the development of various types of sensors and computer-based controllers capable of interacting with these sensors and other manufacturing equipment.

This control and sensor feedback concept is now being applied to other manufacturing equipment and is referred to as the Next Generation Controller (NGC). The use of sensory feedback with appropriate information processing capabilities enables the equipment to react, even to anticipate changes in the material, the process, or the equipment itself which could affect the consistency of the item produced. Consistency is critical to the productivity and control of the manufacturing process and the quality of the goods produced. For example, intelligent processing equipment virtually eliminates the need for post-inspection. The net effect is lower manufacturing costs with increased product quality and reliability — keys to world-class competitive manufacturing capabilities. Other National Critical Technologies that have important roles associated with intelligent processing equipment include software, high-performance computing, electronic imaging and displays, and optoelectronics.

Intelligent processing equipment requires a thorough knowledge of the process and relies on intelligent control systems which react to input from advanced sensors. Some sensors are able to react directly to the environment to detect states and situations. In many cases, however, the nature of the manufacturing process is such that the desired variable cannot be measured, and a combination of several indirect indicators must be used. In such cases, and where many variables interact to affect the process results, artificial intelligence technologies, fuzzy data, and neural network techniques are used. In addition, the control system interacts with automated management tools and manufacturing information systems to coordinate the next level of factory operation (see ***Flexible Computer Integrated Manufacturing*** and ***Systems Management Technologies***). Thus, sensors and control systems, coupled with artificial intelligence and an understanding of process variables, are critical to intelligent processing equipment. The mechanical elements of intelligent processing equipment include manipulators and actuators, precision mechanisms, machine vision systems, nonvision sensor systems, and assembly/ inspection systems.

One of the most important technological components of intelligent processing equipment is the controller -- the "brains" of modern automation equipment. Controllers use advanced processor chips and software languages and tools to command and control multiple functions simultaneously to achieve higher efficiencies in manufacturing. In the area of machine tools, advanced controllers monitor and manipulate axes of motion to high accuracies at relatively high speeds. Broader mechanical functions typically "controlled by the controller" include machining, machine setup, intra-workstation materials handling, and part inspection, grasping, and fixturing, as well as task planning and process programming. A non-mechanical example illustrating the range of controller functions would be advanced autoclaves, in which controllers control temperature and pressure while monitoring the curing process.

Sensors provide the inputs needed for these machines to perform their functions. Sensors are needed to provide real-time information that can assist controllers in identifying potential bottlenecks, breakdowns, and other problems with individual machines and with a total manufacturing environment before they upset production. Accuracy and repeatability are critical capabilities, without which sensors cannot provide the reliability needed to perform in advanced manufacturing environments. To be useful with intelligent processing equipment, sensors must be able to discern weak signals while remaining insensitive to other interfering impulses. Sensors must be able to ascertain conditions instantaneously and accurately, and provide usable data to system controllers, without whose processing capabilities these inputs would be useless. Many types of sensors are utilized in intelligent processing equipment. Four examples are:

- Sensors that can detect the presence or absence of a component or characteristic of a part by recognizing physical characteristics such as color, size, or shape within a reasonably short cycle time. Machine vision and proximity sensors are used for such applications. Critical considerations for such sensors include accuracy in the determination of precise dimensions and the ability of the system to perform accurate operations repeatedly over prolonged periods
- Sensors such as photoelectric and ultrasonic sensors that enable intelligent processing equipment to position and set functions
- Sensors that are used for monitoring equipment operations. These can include condition sensors (used to determine operation temperatures, vibrations, etc.) and position-monitoring sensors (for counting product output and timing of operations). Monitoring sensors are especially important in diagnostics — monitoring and anticipating conditions that could lead to equipment breakdowns or other system dysfunctions
- Sensors that can be used for status and part identification. Bar code and RF systems, for example, frequently are used for status and part identification. Part identification tells controllers what operations to perform.

Future sensors necessarily will be more advanced and "smarter" in terms of their ability to measure, evaluate, and assess precise physical, mechanical, and chemical characteristics of a product.

Machine vision is also an important component of intelligent processing equipment. Potential uses of machine vision systems illustrate the vast range of applications of sensor-based systems in manufacturing. Such systems can be used in virtually any location and spatial relationship in production, and in determining dimensions for parts and assemblies having specified tolerances. Representative examples include:

- Lead bonding for microelectronic chips
- Mask and reticle inspection in integrated circuit manufacture
- Printed circuit board, solder joint, and wafer/ diode inspection
- Arc welding
- Automated vehicle systems

- Assembly
- A variety of dangerous manufacturing tasks on the shop floor.

REASONS FOR SELECTION

Present-day processing is based upon the assumption that controlling process and equipment variables within predetermined ranges and relationships will ensure that the process results in a consistent product. Historically, consistency of output was accomplished through the use of "fixed" automation, which was used to produce a large volume of a single product over a long period of time. But fixed automation is both too slow to change and too costly, except for some high volume products with long product lives. Today's market is being driven by customers and competitors who are responsive to large product varieties and rapid introduction of new products. In the past, the use of highly skilled and experienced machine operators was the only approach available to produce the low-volume, high-variety products — a costly approach no longer effective in this country. Thus, the trend in manufacturing is toward more rapid product realization, increased flexibility, and integrated design-production-quality control. Manufacturers lacking intelligent manufacturing capabilities will become increasingly noncompetitive in many industries; as a consequence, they increasingly will demand these capabilities from their domestic and foreign manufacturing equipment suppliers.

It is impossible to maintain competitive manufacturing capabilities, particularly in high technology fields, without having indigenous access to a broad range of state-of-the-art equipment. Equipment suppliers in the United States are losing market share to international competitors in a broad range of fields, including fabrication equipment, machine tool controllers, semiconductor manufacturing and test equipment, and large-scale presses. Although effective management can offset some of the disadvantages of less-than-competitive equipment, foreign competitors have access to both effective management and up-to-date equipment. Further development and deployment of intelligent manufacturing technology will be required if the U.S. is to regain its traditional leadership position in manufacturing.

It should be noted that the health of manufacturing equipment and supporting sectors are closely related; a large number of technologies are required to adequately support our manufacturing base. As an illustration, advances in control devices represent perhaps the greatest potential for increasing the capability of intelligent processing equipment in the future. Improvements in processing speed and supporting technologies such as graphical programming and high-level languages are allowing more and more functions to be performed automatically by controllers as an integral part of the manufacturing process. Thus, these advances contribute to increased productivity and higher, more repeatable quality, which give users a competitive edge. It is also anticipated that spin-offs from these intelligent processing technologies will impact other segments of the U.S. economy such as agriculture and the service sector. Examples include smart tractors, and service robots for health care, security, cleaning, and fire fighting.

STATUS AND INTERNATIONAL TRENDS

Although the United States had early leadership in developing and marketing programmable, automated machinery, its market had been significantly reduced by the mid-1980s. Foreign manufacturers, particularly Japanese, have come to dominate the world market and take an aggressive position in developing next-generation products. There has been a loss in market share in underlying technologies as the production of intelligent processing equipment has moved offshore. In Japan, this field is more commonly referred to as "mechatronics," which is the integration of mechanical and electronic technologies. It is therefore not surprising, for example, that the U.S. controller industry has been faced with significant competition from both the Europeans and the Japanese, and has steadily been losing both market share and technological leadership. As a result, considerable attention is now being given in the United States to the development of Next Generation Controllers (NGC) which will provide improved performance and greater flexibility to a wide range of users.

Further development of process technology is necessary for the widespread utilization of intelligent processing equipment, especially for the new engineered materials being developed. Such added knowledge will lead to the development of new machines aimed at improvements in productivity and process precision. Another requirement is for the development and application of smart sensors and related software tools such as neural networks, pattern recognition techniques, etc. Overcoming existing limitations in these areas will result in more capable systems that can be used for a broader range of applications. In the interim, simpler technologies and techniques derived from robotic technologies can be introduced incrementally to facilitate deployment of intelligent processing equipment. An example of these trends is the new composite fiber placement machine which is one of the first pieces of equipment to combine the technologies of machine tools and robotics into a new intelligent processing machine for aerospace structures and engines.

MICRO- AND NANOFABRICATION

DESCRIPTION OF TECHNOLOGY

Micro- and nanofabrication involve the fabrication and manipulation of materials and objects at microscopic (microfabrication) and atomic (nanofabrication) levels. Microfabrication involves the fabrication and manipulation of materials on a scale of less than one micron (one micron = 10^{-3} mm). Microfabrication processes include lithography, etching, deposition, epitaxial growth, diffusion, implantation, testing, inspection, and packaging. Nanofabrication includes some of these techniques (ion beam lithography, for example), but also involves atomic-scale tailoring and patterning of materials to utilize their natural properties in achieving desired results. Nanofabrication-scale structures are 10 to 100 nanometers (nm) and smaller (one nanometer = 10^{-6} mm).

Micro- and nanofabrication techniques are essential in semiconductor device production to achieve the densities necessary for the next generation of integrated circuit chips. Expected applications include high-density integrated circuits, optoelectronic devices, quantum devices (where the quantum properties of materials themselves affect device design and performance), textured surfaces for biotechnology (see ***Applied Molecular Biology***), optoelectronics (see ***Microelectronics and Optoelectronics***), and a wide range of other uses. Research in advanced nanotechnology may also lead to the production of nano-scale mechanical devices and sensors.

Integrated Circuit Applications

Micro- and nano-scale manufacturing presents formidable challenges at the scientific level and in processing equipment development. However, breakthroughs in this field would enable the production of integrated circuits and other devices with functional capabilities orders of magnitude beyond those currently in use.

The key to efficient and powerful microelectronic devices is switching speed. Current sizes and distances among devices and components limit performance capability. Micro- and nanofabrication techniques can be used to compress those distances and sizes, thus improving performance. Quantum effect devices, for example, theoretically could have channels as small as 100 atoms in width, smaller than a biological cell.

Nanolithography techniques are a critical element of nanofabrication. At present, it is done using scanned, focused electron or ion beams to develop patterns on a wafer surface. Because of the microscopic detail required to produce devices of this sort, a formidable barrier in nano-scale manufacturing is developing techniques that can etch circuit patterns without damaging materials themselves. In scanned electron-beam lithography, for example, incident electrons, after passing through a resist, scatter back through it, causing broadening of the pattern. (A similar problem exists for focused ion-beam lithography, although it can result in greater pattern precision.)

Other challenges in nanofabrication include developing substrate materials and patterning structures to optimize characteristics conducive to nano-scale fabrication.

Thin Films/Surface Treatments

Thin films consist of microscopic layers of materials deposited or otherwise fabricated on the surface of other materials (substrates). Surface treatment technologies focus on processes that modify the surface of a base material to produce a thin film or coating on a surface to utilize the advantages inherent in the physical properties of the respective materials. Microscopically applied films and surface treatments are utilized in a number of areas. Coatings are applied, for example, to turbine blades in aircraft engines to reduce wear. Bearings can be treated to produce surface coatings that reduce friction. Films themselves can be fabricated as part of an integrated circuit. Cutting and drilling tools are coated to protect against wear. Both thin films and surface treatments can be utilized to overcome limitations in materials and provide improved performance in terms of wear, heat resistance, and corrosiveness. A key production factor is the ability to fabricate a microscopically thin, dense, and uniform surface.

Diamond films illustrate the promise of microfabricated films. A diamond's physical, electrical, optical, thermal, and electronic characteristics are superior in many respects to those of other materials. Its remarkable properties include higher thermal conductivity (five times that of copper at room temperature, for example), hardness that is orders of magnitude higher than many other coating materials, and greater electron mobility, making it suitable for a variety of electronic applications. The key to microfabrication is in using this material in minute quantities to capitalize on its superior properties while also utilizing the desirable qualities of other materials to which it might be bonded in various fabrication processes. Diamond films fabricated through deposition and other techniques can be used to harden drilling and cutting tools or to produce more efficient semiconductor devices and microwave circuitry. Other potential applications include bearing coatings, heat sinks for high power integrated circuits, and optical components for high power lasers. Aerospace applications include the use of diamond films to reduce wear on space-rated alloys and radiation resistant optical coatings.

Physical vapor deposition (PVD) and chemical vapor deposition (CVD) are two common techniques used in creating thin films on substrates. PVD applies films to substrates through such techniques as evaporation and sputtering (ion bombardment of a target to deposit displaced material onto the substrate). CVD relies on processes by which a film is created on another material through chemical reaction between a gas and the heated surface of the substrate itself. Other deposition processes include spin-on deposition (which involves dropping a liquid onto a spinning substrate for even distribution of the material, followed by pyrolysis to cure the film).

Micro-Mechanical Devices

Advances in micro- and nanofabrication techniques have enabled the development of a new class of devices of microscopic dimensions that are capable of performing a range of functions in fields as diverse as environmental control and medical science. Their potentially low cost coupled with sensitivities orders of magnitude beyond the capabilities of devices currently in use promise breakthroughs in numerous fields. Electrostatically driven micromotors, for example, could be manufactured in the future to control computers and communications systems. Microsensors could be used to measure flow, pressure, or concentration of various chemical species in environmental, medical, and mechanical applications.

Advances in manufacturing techniques must be matched by improved material fabrication methods to facilitate the widespread production and utilization of microdevices. The high stress levels in these devices require the development of new materials and improved processing of existing materials to assure reliable operation and high performance. Greater understanding of the mechanical properties of these materials is also necessary before they can be utilized to their full potential (many of the materials now used to manufacture demonstration devices are semiconductor materials which have been used in the past primarily for their electrical properties). Finally, design know-how must be enhanced to minimize defects that affect microdevice manufacture and operation.

Although U.S. capabilities in thin film and microdevice production are advancing rapidly, greater benefits will accrue to the nations that excel in the design and manufacture of equipment needed to produce these materials and devices economically and in mass quantities. Just as in the semiconductor and other industries, basic know-how and production technologies are interrelated. Failure to make advances in one area could preclude strides in the other, ultimately hampering the ability of a nation to remain competitive in the overall field.

REASONS FOR SELECTION

Semiconductors and integrated circuits are the fundamental building blocks of the information and communications industry and form a foundation for many other industries that are essential to today's economy and to the U.S. defense posture. Advances in the area of integrated circuits and other microelectronic devices drive downstream capabilities and applications in information industries. The next generation of integrated circuits will move toward greater utilization of manufacturing processes at micro- and nano-levels, thus requiring U.S. firms to make continued efforts to remain viable competitors.

Advances in the basics of micro- and nanofabrication must take place in tandem with improved manufacturing equipment capabilities required to produce such devices. The U.S. semiconductor industry is dependent on an infrastructure of equipment suppliers, and the nation that leads in processing equipment innovation is likely to dominate the world market for semiconductor devices.

STATUS AND INTERNATIONAL TRENDS

Progress in a wide range of technologies is required to attain the benefits of micro- and nanofabrication capabilities. Nanofabrication processes are likely to be highly application-specific; each process will be effective and appropriate for only a group of materials or production problems.

Although U.S. efforts in nanotechnology remain strong, Japan leads in certain areas such as nanolithography. New semiconductor devices produced by utilizing advanced X-ray lithography, for example, are expected to be commercialized by Japanese firms in the early part of this decade. This will assure that Japanese firms will be able to retain their present market share in this critical industry and extend their lead in advanced memory chips and other microelectronic devices. Fabrication technology with one micron feature size is already relatively mature; X-ray lithography technology in Japan is reportedly capable of manufacturing at scales of 0.3 microns. One Japanese firm's research in microscopic and atomic scale manufacturing has led it to launch development of 256M memory chips.

Japan already has more than a 50 percent share of the global semiconductor market. The three top suppliers of semiconductor manufacturing equipment in the world are Japanese firms, their total sales representing 43 percent of global equipment sales for the top ten manufacturers. This provides Japanese firms massive financial resources to fund semiconductor manufacturing R&D. Because of the immense capital investments required (for a single, first generation X-ray lithography plant, the required investments might be on the order of $1 billion) and the highly advanced nature of the technology, failure to at least remain abreast of overseas competitors could threaten permanent loss of the industry for the United States.

SYSTEMS MANAGEMENT TECHNOLOGIES

DESCRIPTION OF TECHNOLOGY

Systems management technology (SMT) is often thought of as a scientific discipline or as a management approach rather than a "technology" or set of technologies. Systems management technologies do indeed involve extensive modifications of management and organizations, to allow more effective integration of the diverse functions carried out by a manufacturing enterprise (e.g., market research, product design, manufacturing operations, quality control, marketing, and customer support). However, new information technologies are fundamental enablers of advanced systems management concepts. The area includes tools, practices, and sciences that will become increasingly important as advanced manufacturing systems become the standard. As with many of the other technologies included in the "Manufacturing" category in this report, systems management technologies are intertwined with other National Critical Technologies, including several in the area of "Information and Communications." Failure to achieve advances in these related technologies and to incorporate them promptly in manufacturing operations and processes will retard the potential development of SMT.

Within the manufacturing hierarchy outlined in ***Flexible Computer Integrated Manufacturing***, SMT is directed at the intra- and inter-enterprise level rather than toward specific manufacturing operations. Because of the large number of technologies that this area can involve, this section highlights a few that are in current use and are expected to grow in importance in the future.

Product Data Exchange Tools

The ability to exchange computer information within and among business units is central to successful diffusion of systems management technologies throughout industry. Early computer data exchange systems such as Initial Graphics Exchange System (IGES) allow different computer aided design (CAD) systems to exchange two- and three-dimensional geometric data. PDES (Product Data Exchange using STEP) is expected to advance the field by enabling the smooth exchange of total product data, including information about the design, production, support, and other stages of the product's life cycle. (STEP is the evolving international Standard for The Exchange of Product model data.) Although these tools are not perfect, they represent steps toward allowing different CAD and computer aided manufacturing (CAM) systems to communicate with one another, and represent technologies that are essential if the benefits of flexible computer integrated manufacturing (CIM) are to be realized fully. Future systems, or variants of existing systems, will become on-line databases to allow more than a simple exchange of information.

Databases

Computerized tools are required to manage and control CIM and flexible manufacturing systems (FMS). Typically, these include extensive databases on various components of manufacturing processes, including system and individual machine performance.

Data-Driven Management Information Systems (DDMIS)

DDMIS involves the storage and use of designs, inventory/order information, and information on capabilities of different machines to design and manage flexible CIM. Using such inputs, managers and engineers can generate up-to-date reports on the utilization of the system, inventory and production status, demand levels, personnel information, and financial information.

Interoperable Information Systems

The continuing evolution of a national framework for enterprise integration architectures increasingly will permit smooth interoperability of information products from multiple vendors. Today, tight integration of software and computer hardware, even from a single vendor, is difficult to accomplish on anything but the smallest scale. Integration architectures, implemented through national and international standards, will stimulate further integration, with competition shifting to functional performance rather than implementation and support factors. Greatly increasing the degree of integration, often called Factory C^3 (command, control, and communications), will result in far greater efficiency in all intra- and inter-enterprise functions, and represents a powerful tool for abbreviating the time for new products to reach the market, reducing costs, improving quality, and enhancing flexibility. Truly interoperable information systems will allow extensive networks to tie together all elements of a corporation, along with its supplier infrastructure, trading partners, and customers. Such networks will encompass distributed data bases and distributed processing, which in turn will allow better decisionmaking through broad access to more accurate and timely technical and business information.

These independent technologies and tools individually and collectively provide automated decision support, throughout an enterprise. They allow the more effective linkage of design, production, and other functions.

In addition to technology, significant changes are taking place in manufacturing management practices. New strategies, such as continuous improvement, are being coupled with participatory management philosophies and total quality management. However, large-scale integration of all computer-based systems that support design, manufacturing, and business functions is extremely complex and not well understood.

REASONS FOR SELECTION

Increasingly, modern manufacturing emphasizes rapid product design and introduction, reduced inventories, smoother process flows, faster turnaround times between production runs, and the elimination of other traditional buffers. More efficient manufacturing results in reduced down times, but also creates the need for more efficient planning and operation because there is less margin for error. As a result, managers of the future must be more skilled at developing and implementing manufacturing strategies in totality, rather than as a series of isolated, sequential steps and decisions made by individual components of manufacturing entities.

Effective Japanese utilization of advanced manufacturing equipment and systems could exceed that of the United States in the near future. Typically, U.S. managers view automated equipment and systems as replacements for older tools, rather than as a means to provide a new manufacturing approach or to integrate the new equipment and systems into a new manufacturing system. Since traditional U.S. managerial attitudes and practices often retard the development and utilization of intelligent processing equipment and flexible CIM, emphasis must be placed on sciences and technologies that will help managers identify and take best advantage of the strengths of such systems.

In this regard, industry must focus more attention on such concepts as the management of change and the management of technology. Introduction of even state-of-the-art equipment will not produce desired results without incorporating the managerial philosophies represented by such systems. This poses an educational challenge that is equal to the technological challenges posed by the development of advanced hardware needed in flexible manufacturing systems.

Furthermore, no single technical solution can be copied or acquired easily in automated manufacturing. Much of the success in other countries with automated systems has resulted from incremental improvements in processes and production technologies, not in the development of a single "untailored" device or managerial philosophy. It is not reasonable to expect U.S. businesses to be able to make only a handful of changes or adjustments in their methods of operation and reap a multitude of rewards as a result. Flexible CIM systems are enterprise-level initiatives -- not just production subsystems -- that require expertise and skills among managers, designers, and workers. Each industry and enterprise faces unique challenges and needs. Development of a skill base through systems management technologies to address these needs will enable future managers and production specialists to address a broader range of problems facing industry today and in the future.

STATUS AND INTERNATIONAL TRENDS

There is considerable worldwide emphasis on the development of improved systems management technologies. One effort, for example, is exploring the use of expert systems and artificial intelligence systems to expand the capabilities of computer-assisted material requirements planning (MRP) and manufacturing resource planning (MRP II). However, many expert and artificial intelligence systems are available, yet underutilized, today. A common feature of these technologies is the high degree of concurrence in the definition of product specifications, development of product design, and the development of production system specifications and designs. This contrasts with traditional tendencies to treat these considerations as isolated, incremental steps in the decision making process. Thus, major changes in an enterprise's outlook and practices are required in order to optimize their use.

Many of the "technologies" described here include philosophical components, without which their potential advantages will be lost. A commitment to the effective management of technology is essential in order for these tools to deliver full benefits for their users. While passive or lackluster utilization will minimize their potential benefits, aggressive and comprehensive implementation of such philosophies can increase the benefits of highly integrated and automated systems.

Japanese manufacturing enterprises have pioneered in the development of advanced systems management concepts and the technologies needed to facilitate enterprise integration. U.S. efforts in development of integration technologies are at least equal to Japan's, but it is widely believed that traditional U.S. management concepts are less amenable to widespread implementation of these capabilities. The culture and management practices of many U.S. companies must change if the United States is to remain strong in today's manufacturing environment. This need is being recognized, and industrial organizations along with engineering and business schools now have programs focused on the management of technology.

INFORMATION AND COMMUNICATIONS

- Software
- Microelectronics and Optoelectronics
- High–Performance Computing and Networking
- High–Definition Imaging and Displays
- Sensors and Signal Processing
- Data Storage and Peripherals
- Computer Simulation and Modeling

INFORMATION AND COMMUNICATIONS

This area encompasses a wide range of advanced technologies that are critical for virtually every function performed by an increasingly "electronic" society. The seven Information and Communications technologies designated as National Critical Technologies are pervasive, and will play a substantial role in determining the rate of progress in other critical technology areas. For example, sensors, software, simulation and modeling, and computing are increasingly becoming the critical underpinnings for advanced manufacturing processes. Similarly, information technologies also enable or limit advances in the performance of next–generation weapon systems, military training, and the planning and execution of military operations.

In turn, further advances in information technologies are highly dependent on continuing development of materials and manufacturing technologies. Electronic and photonic materials, materials synthesis and processing, and micro– and nanofabrication technologies are especially important for future–generation information technologies.

The information and communications technologies are both important to and dependent on other technology areas. For example, continuing advances in microelectronics and optoelectronics, software, and data storage are essential enabling technologies required to achieve potential advances in high–performance computing. However, simulation and modeling (itself an essential underpinning for most other National Critical Technologies) depends on substantial advances in software, computing, and other information technologies.

Because of the pervasive nature of these technologies, the strong international and technological challenges faced by U.S. producers in this technology area tend to cascade throughout the economy. Maintaining state–of–the–art capabilities in information technologies will, without question, determine the economic performance of increasing numbers of segments of the U.S. manufacturing and service sectors.

SOFTWARE

DESCRIPTION OF TECHNOLOGY

Computer software is pervasive in modern society. Advanced software permits computers to solve problems, manipulate data, and create new data or visual displays on a computer screen. It manipulates sensors, robotics, and other automated machines to perform useful work. Software is the basis for countless applications in information handling, manufacturing, communications, health care, defense, and in research and development.

Increasingly, the development of advanced software is an important limiting factor in the introduction and reliability of new military and commercial systems. Software requirements, as well as development costs, expand at a dramatic pace as automated systems proliferate and increase in sophistication. Despite these growing demands, the generation of advanced software programs remains largely a painstaking, labor-intensive task. As a result, the ability of U.S. industry to provide high-quality, reliable software is in jeopardy.

The economic infrastructure of the United States is largely dependent upon highly complex software which frequently contains errors. In 1990, a "minor" programming flaw resulted in a nine hour shutdown of the major U.S. long-distance telephone network. As systems become more automated and complex, there is a real likelihood of more frequent failures in key systems and services. Advanced software therefore poses a paradox: a fundamental source of technological progress, it is also a growing source of technological vulnerability.

This paradox is especially acute in the defense sector, where software plays a vital role in ensuring the technological preeminence of U.S. military systems. Software problems have plagued many critical defense systems — frequently resulting in cost overruns, program delays, and serious operational failures. To a great extent, these problems are a result of the demanding specifications and unprecedented complexity of many military software applications.

Software Engineering Tools

To resolve these problems, programmers need sophisticated tools to facilitate the efficient design and generation of low cost, maintainable, complex, and reliable software. The development of computer aided software engineering (CASE) tools, user interface design tools, advanced software design methodologies, software testing tools, and manufactured software concepts are needed to supplement -- not supplant -- the remarkable ingenuity of programmers. These tools are necessary to ensure that software remains an engine of, rather than a bottleneck to, future technological growth.

Unlike other products, the essence of software is in its design -- the development of software requires no extensive fabrication or assembly. As a result, software development is dominated by the task of designing the program to ensure that it will perform all of its desired tasks. However, it is frequently difficult for programmers to anticipate all of the circumstances that may arise when the program is executed. Moreover, given the complex interactions of the software in sophisticated programs, it is frequently difficult to develop a "maintainable" software structure -- one that can be easily modified to add capabilities or eliminate programming errors without risk of creating an unforeseen, and perhaps devastating, flaw in the program.

CASE tools can help remove much of the guesswork and experimentation in software development, thereby contributing to the efficient production of high-quality programs. These tools are themselves sophisticated software packages that help programmers define the requirements of a program and design its structure. CASE helps the programmer anticipate the variety of tasks that are likely to confront the program, and tailor the software package to facilitate software maintenance. In addition to developing the design of the program, some CASE tools also have the capability to generate simple programs based on the specified design. Automated coding for sophisticated software packages remains a key technical challenge.

Because of the great number of internal states and combinations of input and sequence conditions, complex software cannot be exhaustively tested prior to release. The multiplicity of variables has produced a "combination explosion" which makes it impossible for programmers to anticipate every circumstance that may confront the program. Intensive efforts are underway to develop advanced testing tools that attempt to simulate the broadest possible set of conditions in which a program might operate. By reducing manual quality control requirements, these tools have the potential to greatly shorten the software development cycle and reduce development costs.

A central function of software is to render the capabilities of the hardware fully accessible to the user. Video displays and other forms of user interface require highly complex software, a result of the enormous data requirements to form an accurate and responsive display image. In fact, user interface frequently accounts for half of the program code in sophisticated software packages. User interface design tools have been developed to design and generate much of the interface software, allowing the programmer to concentrate on highly specialized features of the interface. These tools also facilitate the integration of the interface software with the rest of the program.

Innovative Concepts

In addition to these software-based design tools, new management concepts for software design and development are contributing to more efficient production of high-quality software. One such concept is rapid prototyping. The traditional software development methodology is known as the "waterfall" model, a sequential process beginning with requirements definition, followed by structure definition, code generation and, finally, testing. Frequently, however, the future user cannot fully anticipate all of the desired functions of the program until he/she actually begins to employ the product. As a result, the program requirements must frequently be redesigned, resulting in delays and difficulties in integrating new program elements with the existing software. In rapid prototyping, program designers, user interface specialists, and end users work together from the outset of the software development process to produce, in a relatively brief period, the essential elements of the desired software. After the user is fully satisfied with the core program elements, the program is expanded and refined. Rapid prototyping yields significant benefits in terms of fewer iterations, reduced development costs, and improved software quality.

Modular software is another software development concept with important potential for boosting productivity and quality. By breaking complex software applications into smaller sections (or modules), the complexity of the overall task is reduced. In addition, a proven module can often be reused in subsequent applications, further enhancing reliability and cost-effectiveness. Increasing use of object-oriented programming is reinforcing the trend toward greater software modularity. Object-oriented techniques provide a mechanism to better formalize a model of reality. Software written in object-oriented languages is inherently reusable. Like other modular approaches, object-oriented software reduces the total life cycle software cost by increasing programmer productivity and reducing redesign or modification costs.

Advanced software design tools and methodologies have strong potential to transform software development from a labor-intensive craft into a more highly automated production process. With such advances, the **writing** of software can increasingly give way to the **manufacturing** of software. The development of a mature manufactured software industry is integral to satisfying the expanding needs of business and defense for complex programs.

REASONS FOR SELECTION

Modern, highly-automated systems are becoming more dependent on the reliability and advanced performance of software. The cost of such systems is also increasingly affected by software development and production costs.

The ability to efficiently produce high-quality software is the key to a wide range of advanced technologies in industry and defense. Modern information and telecommunications systems -- as well as the air-worthiness of U.S. military aircraft -- are virtually dependent upon the flawless operation of highly sophisticated software. Moreover, advanced software is fundamental to basic research in a variety of disciplines. In short, software is a key enabling (or inhibiting) factor in many of the National Critical Technologies. Current manpower intense, trial-and-error design methods are likely to increase system costs and performance problems as the software challenges become more acute.

STATUS AND INTERNATIONAL TRENDS

Software is a traditional strength of the United States. U.S. programmers are widely considered the most ingenious and creative in the world. During 1988, the global software market grew by 23 percent to $55 billion, with a U.S market share of 60 percent. The traditional U.S. lead in software development and applications has been a key factor in maintaining competitiveness in information technology and other vital sectors. However, overseas competition is intensifying. Europe's software capabilities are expected to strengthen as a result of current standardization activities associated with the EC '92 initiative. Additional competition is generated by some third world nations, which offer lower labor costs than are available in the United States. Japan may pose the greatest competitive challenge. Some Japanese companies are producing large quantities of software in highly structured, strict writing operations set up much like product manufacturing plants.

The central challenge in software development is automated code generation for sophisticated programs. The development of such tools is largely dependent upon artificial intelligence and other software-based technologies. Further advances in design tools, testing devices, and modular software are also considered crucial in increasing the productivity and reliability of the software development process.

MICROELECTRONICS AND OPTOELECTRONICS

DESCRIPTION OF TECHNOLOGY

Microelectronics and optoelectronics have accelerated advances in all fields of knowledge by providing ever–increasing capabilities to process, transmit, and disperse information. Products based on microelectronic and optoelectronic technologies have stimulated advances in such diverse areas as communications, manufacturing, defense, education, health care, transportation, and entertainment.

The distinguishing characteristic of this technology is the microscopic size of the individual electronic elements, millions of which can now be imprinted on a single semiconductor chip. Today's chips have minuscule energy requirements and unit costs, and offer ever–increasing operating speeds and reliability. Continued success in miniaturizing individual elements and integrating larger numbers of these elements into more efficient and reliable packages are critical goals for semiconductor product technologies. Another critical goal is to further develop and improve the cost–competitiveness of new materials, including gallium arsenide and other compound (non–silicon) materials, so that they are available for use in special applications. (See ***Electronic and Photonic Materials***.)

The low unit cost of today's semiconductor integrated circuits (ICs) results from the opportunity to spread production costs over large quantities of chips, each having thousands or even millions of elements. However, the low unit cost belies the enormous (and increasing) cost and complexity of IC manufacturing. Microelectronics production involves some of the most intricate and exacting operations found in manufacturing today. Production of a typical integrated circuit requires several hundred separate steps in which delicate wafers must be manipulated repeatedly, with tolerances maintained at microscopic scales. Manufacturing must take place in an extraordinarily clean environment so that high production yields can be obtained. Goals for semiconductor manufacturing include improving currently used processes and developing new processes (such as X–ray lithography and advanced etching techniques) to produce more versatile IC products at lower costs.

Optoelectronics is a relatively new technology that will extend the performance of conventional electronics. Within the general area of photonics, optoelectronics encompasses devices that respond to optical power, emit or modify optical radiation, or utilize optical radiation for their internal operation. Optoelectronics also includes any device that acts as an electrical–to–optical or optical–to–electrical transducer. These functions can be carried out by a variety of devices and circuits, including lasers and other light sources, optical fibers, electro–optical devices, and electronic circuits. Applications include industrial processing, telecommunications, signal processing, medicine, imaging, computing, analytical instruments, military surveillance, and guided weapons. The design and performance characteristics of optoelectronics, such as power, speed, efficiency, wavelength, spectral linewidth, coupling efficiency, temperature range, lifetime, and cost, vary with the requirements of a particular application. Generally, the more formidable the application, the more complex and expensive the system.

Some of the most exciting advances in the field of optoelectronics are in laser technology. Lasers have become essential tools in manufacturing, research, medicine, information storage, printing, and measurement and testing. In medicine (see ***Medical Technology***), lasers already are widely used in surgical procedures and will find future use in correcting vision defects by reshaping the eye's outer optical surface and in dental applications to identify and eliminate plaque. In manufacturing, lasers are used to drill holes that have a diameter narrower than a human hair.

One of the most useful lasers is the semiconductor laser or diode laser. First demonstrated in the United States, the largest number of these lasers are now being produced in Japan for applications that range from low–cost compact disc players to complex long–distance communications systems.

This type of laser is built from a single semiconductor chip, where all of the laser's electrical and optical functions are performed. Its small size, durability, low cost, and long life distinguish this from other laser technologies and have allowed it to revolutionize fiber optic communications systems, optical memory devices, and home entertainment (such as compact disc players). Laser diodes also have defense applications. Laser diode arrays, which provide more light output than is possible from a single diode laser, provide increased efficiency and compactness within individual devices. Incoherent (unphased) arrays are being used as an alternative pump source for solid state lasers, while coherent ones have found use in optical radar, satellite communications, directed energy, and antisubmarine warfare.

Given the dynamic pace of development for microelectronics and optoelectronics, there are innumerable advances that will increase the use and effectiveness of these technologies in future applications. As an example, one promising area of research is the integration of optoelectronics and information processing electronics on a single chip. The creation of the optoelectronic integrated circuit (OEIC) will enable receivers, transmitters, laser arrays, and other assemblies of tens and hundreds of photonic and electronic circuits to be realized on a single substrate. With progress in materials technology, microelectronic and optoelectronic systems will be able to improve performance for thousands of vital information and communication-related products. Another example is the extremely important area of packaging and interconnection. With the expanding demand for pin-outs and the quest for ever higher speeds on these pins, much of the improvement in the future will rely on advanced packaging and interconnection technology.

REASONS FOR SELECTION

Electronics-related technologies are arguably the most pervasive of all technologies. Nearly every other technology that can be envisioned looks to microelectronics as one of its essential building blocks. The direct impact on other technologies is evident in the fact that electronic and microelectronic components are integral to virtually all advanced manufacturing, information and communication, and aerospace and transportation systems. In the case of computing, new photonic technologies may in the future replace the all-electronic computer and assume the lead role as the technology of the future.

Applications of both microelectronics and optoelectronics will continue to refine and eventually transform the way we live by providing improved communications, stronger defense capabilities, and innovations in medical services. Today, electronics is the largest and fastest growing manufacturing sector in the United States. Advances in its underlying technology base are clearly important to U.S. competitiveness in world markets, since they enable development of new products and improvements in the cost, quality, and performance of existing ones. Advances in these technologies are revolutionizing production processes and factory management through the integration and control of manufacturing operations. In defense, microelectronics and optoelectronics are no less critical to "smart" weapons and to command, control, communications, and intelligence functions. Advances in this technology also improve products and services in such areas as health, human welfare, and the environment.

STATUS AND INTERNATIONAL TRENDS

Although both microelectronics and optoelectronics had their beginnings in the U.S., the Japanese have assumed a strong role in product development, manufacturing, and sales.

In photonics-related technologies, Japan is the world leader and now has two-thirds of the world's market for semiconductor-based optoelectronic devices. This category includes laser and light-emitting diodes, photodiodes, charge-coupled devices, solar cells, and optical couplers. The main exception to Japan's leadership position is in optical fibers, where the U.S. has dominated the market by effectively integrating R&D phases with manufacturing. Although most of Japan's optoelectronics output is used to support its extensive consumer electronics industry, Japanese firms are applying optoelectronics technology in such areas as telecommunications and data processing. Some of these newer applications will require more advanced optoelectronics technologies, including optoelectronic integrated circuits and photonic switching devices. The Japanese coordinate research through the Optical Computer Group, Optoelectronic Projects under sponsorship of the Ministry of International Trade and Industry (MITI). Japanese firms, with government assistance, are currently linking up with U.S. and European firms and research institutions to gain access to the most advanced optoelectronics developments. In particular, MITI is approaching U.S. and European firms and research institutes for their participation in Japan's Sixth Generation Computer Project -- a key goal of which is the development of optical computing technology.

The position of European firms and research institutes is similar to those of the United States -- taking a lead role in developing state-of-the-art optoelectronics technology but playing a lesser part in commercial applications. European firms, whose efforts are coordinated through the European Joint Optical Bistability Program, have strengths in semiconductor lasers, solar cells, and optical switching and computing. Within the United States, a major portion of optoelectronics R&D is being done by a few companies and several university centers. This research is being funded by the DoD and National Science Foundation.

In microelectronics, the U.S. position is now being seriously challenged by Japan. The United States has already lost leadership with respect to IC sales; in fact, the United States ran a $3 billion IC trade deficit in 1989. While U.S. companies continue to lead the logic and microprocessor markets, Japanese companies now dominate the world market for memory devices, which constitutes the largest single segment of the IC market.

The United States has also lost ground to Japan in a growing number of IC fabrication techniques. The United States still maintains an edge in such areas as ion implantation, thin film epitaxy, thin film deposition, and etching, but has fallen behind in lithography, materials purity, and ceramic packaging. Achieving and maintaining preeminence in product and process technologies is highly capital intensive, and well beyond the practical capabilities of many U.S. firms. Japan appears to have taken the lead in a number of new semiconductor manufacturing technologies, including microwave plasma processing, radiation sources for lithography, electron and ion microbeams, laser-assisted processing, compound semiconductor processing, and three-dimensional device structures.

These trends reflect a serious challenge to U.S. technological leadership, not only with respect to microelectronics and optoelectronics, but also with respect to virtually all other advanced technologies that directly or indirectly rely on those capabilities. The identification of these technologies as among the nation's most critical highlights the importance of efforts to maintain a viable industrial base that can meet the nation's continuing needs for affordable and advanced microelectronic and optoelectronic products.

HIGH-PERFORMANCE COMPUTING AND NETWORKING

DESCRIPTION OF TECHNOLOGY

High-performance computing refers to the development of computer technologies with advanced performance in computational power, storage capability, input/output bandwidth, and software. These objectives can be met through alternative technical approaches, which currently extend from stand-alone "supercomputing" machines to systems that link together a number of processors through the use of "massively parallel architectures." The components of high-performance computing encompass hardware, which refers to electronics and other components that make up the physical computer systems, and software, which includes general-purpose operating systems, tools and utilities (such as compilers), analysis tools, debuggers, and data management systems (see ***Software***). The term "architectures" refers to how the components of a system are organized and interconnected for optimal performance. A final element is networks, which provide the essential links between multiple computing systems. These links support the interactive operation of computers by making the most efficient use of the limited capacity of communications channels.

Network technology is not only essential to high-performance computing, but is equally important to a range of other forms of data, image, and voice communications. Networks operate through the conversion of a binary stream of data bits into an acoustic, electronic, or photonic signal, which may be digital or analog. The signal is transmitted over a network and the data stream reconstructed after reception. In the past, network-related technologies were used to provide remote users with access to centralized mainframe computers or to communicate by voice over the public telephone network. During the past decade, however, data exchange between computers has grown exponentially. Features like automatic funds transfer have radically changed the operations of the banking and finance industries. The technology to allow this kind of data transfer has developed into a huge market of its own and will continue to grow as industries more effectively integrate into global markets. Current industry efforts are aimed at building an end-to-end digital system for future applications. This configuration may include a fiber optic link to the home, providing for a quantum increase in voice/image/data transmission capability as well as a variety of new features.

Fiber optic communication technologies are being developed intensively for combined voice and data applications, and are central to high-performance computing requirements. The advantages inherent in fiber optics are the extremely wide bandwidth (allowing multiple signals to be impressed on a single fiber), low noise, low attenuation, high security, and lack of a delay due to a satellite relay. Fiber optic communications still are at an early stage of development, but a single pair of fiber optic filaments currently can carry over 20,000 phone conversations simultaneously. There is a need to develop a high capacity switching infrastructure and data protocols to take advantage of the capacity that fibers now offer (i.e., to parcel out the stream of bits to the many diverse users).

Within the field of high-performance computing, computer scientists are in general agreement that exploiting parallel computer architectures is the most promising approach to achieving major gains in computing power and reductions in computer cost. Current U.S. parallel computer designs and software are as much as an order of magnitude more powerful than the most powerful existing vector machines; U.S. developmental designs will be as much as a hundred times as powerful as any computer that exists today. Massively parallel computers concentrate in one unit the power of thousands of small processors tightly coupled together. Additionally, the combined network facilitates the interactions and cooperation among machines, permitting more power to be brought to bear on highly complex computational problems than can be obtained from a single machine, with a more efficient use of resources. Among the approaches to parallel processing are multiple instructions, multiple data stream (MIMD), single instruction multiple data (SIMD), very large instruction word (VLIW), systolic arrays, specialized parallel coprocessors, and hypercubes.

Contrary to early expectations, recent work has shown that it is feasible and practical to use massive parallelism on real scientific and engineering applications, such as those found in high-energy physics, weather, and economic modeling. Parallel processing has defense and nondefense uses and is also critical to the development of networks and the perfecting of multiprocessing systems. One particularly promising evolution in parallel processing is the development of personal workstations which will have the capabilities of today's supercomputer. This is made possible by advances in the use of parallelism and technologies such as submicron feature size fabrication techniques for integrated circuits.

Limited parallelism supercomputers will continue to play an important role in high-performance computing. Among their advantages is that they are not currently software limited, as are most massively parallel architectures. However, due to the supercomputer's high cost and the difficulty in exploiting the system's innate capacity, most machines have become highly specialized and therefore are not adaptable for general use. Although advances in integrating both supercomputers and parallel processing will make supercomputing technology more affordable and accessible to a variety of users, the parallel processor is viewed as offering a more flexible and faster system at a much lower cost than a supercomputer. Many believe that parallel processors can serve the widest variety of customers with engineering and scientific computing needs.

REASONS FOR SELECTION

During the last two decades, computing has become pervasive in our society. High-performance computing is the leading edge of computing technology, which in turn supports many areas of science and technology, industry, and defense. There has been a wellspring of new successes in the computing field. Computing has become an integral part of experimental and theoretical research. In industry, computer aided design and engineering techniques are rapidly replacing manual ones. Computer assisted and automated manufacturing is increasing productivity and improving the value and reliability of industrial products, while reducing the time required for engineering and manufacturing cycles. New knowledge and new industries are increasingly dependent upon computing.

Computers constitute a significant portion of the U.S. economy, and U.S. competitive success in the industry is bolstered by leadership at the high-performance end of the market. To illustrate the economic importance of computing: in 1988, the U.S. computer industry accounted for 10 percent of GNP, and almost 10 percent of all capital investment. Continued success is essential to the nation's future.

Critical applications of high-performance computing include prediction of weather, climate, and global change; aircraft (airframe and engine) design and analysis; and life sciences, structural biology, and the design of drugs. High-performance computing technology is also essential to meeting critical national security needs, and both DoD and industry have come to rely on continued acceleration of this technology. Besides being used to improve the design, production, and affordability of weapon systems, high-performance computing is also used as a performance-enhancing component of the defense systems themselves.

The technology also constitutes an important tool for many defense and nondefense industries. Its use in simulation and design now improves the productivity of large industries such as aircraft and automobiles, and is being rapidly extended to other industries as the availability of the new technologies improves. Recent vigorous growth in use of high-performance computing in the electronics, energy, chemical, and pharmaceutical industries illustrates the role of computing in assuring the long-term strength of the U.S. economy. These technologies are also expected to be so deeply integrated into many service industries over the next ten years that independent survival in the industry without advanced computerized systems will be nearly impossible.

In communications, global networking systems that will provide real-time access for data processing capabilities for all interconnected systems represent a final illustration of the breadth of high-performance computing applications. Such a network would contribute to the rapid diffusion of technical knowledge around the globe and increase the availability of international financial and management information for personal and business use. The creation of a global computer network system relies on international cooperation as well as technological change.

STATUS AND INTERNATIONAL TRENDS

Most advances in high-performance computing originated in the United States, and the U.S. retains a strong lead in their development and application. U.S. computer manufacturers have devoted considerable R&D funds to high-performance computing. Additionally, U.S. government R&D funding for high-performance computing is about $500 million annually.

The pace of innovation within this technology continues at a rapid rate. In terms of capability, today's supercomputer is tomorrow's desk-top workstation and the following day's classroom tool. A result of the rapidity of technological change and market expansion is increased international competition. The economic benefits of a strong high-performance computing capability are recognized and pursued by other countries, some of which have formed and funded collaborations between private and public sectors to pursue the technology. Their successes represent increasingly vigorous competition in high-performance computing markets.

The U.S. has maintained its world leadership in supercomputing technology — both hardware and software — and is also the leader in the use of that technology in defense. However, the United States no longer has a clear lead in nondefense supercomputing applications, and competition in the development of supercomputing systems is growing rapidly. Japanese supercomputers, though weak in some areas, have had success in incorporating a number of technical improvements that have improved their competitiveness. For example, the Japanese have made hardware advances in circuitry and in circuit packaging and interconnect technologies. Also, the Japanese are strong in network management and network services. As a result, next-generation Japanese supercomputers will provide serious competition with the most advanced U.S. models. Japan's ability to design and produce massively parallel computers currently lags behind that of the United States, but the Ministry of International Trade and Industry plans to initiate a joint public-private parallel processing development project in 1992 to address Japan's weakness. Although high-performance computer developments in Europe lag behind those of both the United States and Japan, a number of public and private European initiatives are currently underway to develop competitive highly parallel systems.

Additional research and development in advanced software -- an area of long-term U.S. strength -- is also required if the United States is to maintain its leadership position in high-performance computing. New software tools, including application-specific software and other specialized methods and algorithms, will allow high-performance computing systems to be embedded transparently in a distributed environment. The technology base required to build such environments includes software engineering and data management tools, and basic research in high-level languages and algorithms. Improving these capabilities will greatly enhance scientific and engineering software productivity.

Standards represents another area where progress is required in the development of advanced computing and communications systems. Computing and networking face the same dilemma as other new or rapidly changing technologies: although agreed-upon standards are required to allow the widespread diffusion of knowledge, any standards created too early in a technology's development could inhibit future advancements and "lock-in" less-than-optimal solutions. Unfortunately, the answer is not to avoid the establishment of clear standards. The result of an absence of standards could be delayed access to information, impeded professional communications, inability to share information sources and research results, and inadequate coordination of research. In the United States, no single entity (either governmental or private sector) is responsible for the national communications infrastructure which includes the setting of standards. Improvements in this area require that the views of a large number of interested groups be elicited and considered by an international standards setting body, so that technological progress is not unnecessarily delayed.

HIGH-DEFINITION IMAGING AND DISPLAYS

DESCRIPTION OF TECHNOLOGY

High-definition imaging and display technology involves devices capable of recording and displaying images with high degrees of accuracy, clarity, and speed. The goal is to create equipment that uses, to its fullest advantage, the human ability to see both high-resolution images and smooth motion at the same time. In addition to advanced imaging and display capabilities, meeting this goal involves real-time signal processing, high-rate data transmission, and high-density data storage to handle the billions of data bits and computations per second required to generate and display high-definition images.

The most prominent high-definition imaging and display application is high-definition television (HDTV), because of its potential to capture a significant portion of the world video market. A general goal for HDTV development is to provide roughly twice the vertical and horizontal line density possible using current television technology. HDTV's commercial potential is the driving force behind most ongoing R&D in the high-definition imaging and display market. However, numerous other potential applications for this technology exist in such areas as: electronic imaging for document storage; digital photocopying; displays for engineering workstations; desk-top publishing; industrial inspection and monitoring equipment; and battlefield command, control, communications, and intelligence functions.

HDTV is the most demanding high-definition imaging and display application, because it combines requirements for: high resolution; rapid response times; large display size; excellent color, brightness, contrast, and efficiency; and low cost. These requirements generate a need to advance enabling capabilities in five major areas:

- **High-definition vision,** which includes video cameras, document scanners, and computers that synthesize images
- **Real-time signal processing,** including analog-to-digital data converters, digital processors, data compression techniques, and semiconductor memories
- **High-rate data transmission,** involving existing transmission technologies, fiber optic networks, and broadcast satellite systems
- **High-density data storage,** including optical or magnetic systems
- **High-definition displays,** including conventional picture tubes or flat panel displays (such as liquid crystal displays).

This list reflects a convergence of video and computer products, due to the ongoing evolution of consumer electronics from analog to digital technology.

Most of the technologies critical to high-definition imaging and displays are addressed elsewhere in this report. One key technology that is not covered is production of large flat panel displays. High-throughput, low-cost production of such displays will require advances in lithography equipment, circuitry patterning, glass sheet production, and thin-film techniques.

REASONS FOR SELECTION

High-definition imaging and display technology is critical both because it is driving the state of the art for a number of other critical technologies and because it has the potential to become a major component of the electronics market throughout the world. A recently completed study by the Office of Technology Assessment (OTA) found evidence that "HDTV developments are driving the state-of-the-art in several [information and communication] technologies more rapidly than are developments in computers or telecommunications." The report noted, for example, how data storage requirements are more demanding for high-definition imaging and displays than for computers. In fact, the computer field has already begun to adapt data storage technologies developed initially for audio and visual applications. The United States currently holds strong R&D and market positions for most data storage technologies, but has fallen behind in some areas. Similarly, the signal processing demands posed by the high quantities of data needed for high-definition imaging and displays are stimulating advances in some semiconductor and computer software applications.

As another example, the OTA report noted how HDTV could stimulate widespread use of optical fiber networks for signal transmission. While the United States pioneered both fiber optic technology and the technologies needed to drive signals through these fibers, Japan now leads in R&D and production for many of these technologies.

The potential market for high-definition and related products is enormous, amounting to tens of billions of dollars for direct applications and perhaps hundreds of billions of dollars for indirect impacts in other electronics markets. In addition to potentially replacing much or all of current home video equipment, high-definition imaging and display technology is likely to stimulate a variety of other revolutionary changes in the information and communications field. Capabilities in this technology are likely to be important throughout the electronics market rather than just within the home video sector.

Flat panel display technology also has major implications for future military capabilities. The ability to generate higher quality visual images in a significantly smaller space will greatly enhance the capabilities of electro-optical systems used in virtually all military systems. It will improve navigation, guidance, target recognition, and a variety of other functions and provide a means to display the outputs of increasingly sensitive sensor and signal processing capabilities.

STATUS AND INTERNATIONAL TRENDS

High-definition imaging and display technology is a major step in the evolution of consumer electronics from analog to digital regimes. The current status of this evolution does not bode well for the future competitiveness of the U.S. electronics industry. In the past, technological advances in consumer electronics created only marginal benefits in other electronics sectors. However, the rising use of digital technology for consumer products has increased the importance of advances in this sector to the electronics market in general. Continued weakness of the United States in development and production of consumer electronics will become an increasing handicap to U.S. competitiveness in the other electronics sectors.

The U.S. weakness in consumer electronics has already hurt competitiveness with respect to display technologies. Displays for consumer electronics constituted 70 percent of the total display market in 1988, compared to 18 percent for computer applications. The United States is still competitive in a number of flat panel display technologies, including design, basic materials, certain types of manufacturing equipment, and certain types of displays. However, current U.S. resources to advance these technologies fall far short of comparable Japanese resources, so the U.S. competitive position is likely to deteriorate. Worldwide sales of flat panel displays equalled $2.4 billion in 1988 and are projected to increase by as much as a factor of four by the mid-1990s.

The U.S. position with respect to HDTV technology also reflects declining competitiveness. The Japanese began selling HDTV production equipment in 1984 and HDTV systems for the home in 1990. Recording materials, (e.g., movies on video disk) permit commercial introduction without the development of a broader standard. The Europeans undertook a major program to develop high-definition imaging and display technology in 1986 and are not far behind the Japanese. U.S. efforts in this area have been extremely limited, and capabilities are far behind those of the Japanese and Europeans. Moreover, the prospects for a significant increase in U.S. efforts are poor, because the market prospects are too long-term and high-risk to justify a substantial increase in privately funded R&D, and national security requirements alone do not support a major commitment of defense funding.

SENSORS AND SIGNAL PROCESSING

DESCRIPTION OF TECHNOLOGY

Sensors and signal processing allow automated systems to interact with the external world. Sensor and signal processing devices are the core components of vital systems in the fields of defense, aerospace, bioprocessing, human health care, manufacturing, pollution control, transportation, and telecommunications.

Sensors are microelectronic devices that observe or monitor changes in their environment. Sensors respond to a variety of phenomena, including temperature, pressure, and the presence or movement of physical objects. The increasing automation and complexity of computer–assisted technologies places increasing demands on sensors for accuracy, reliability, and responsiveness.

Signal processing technology transforms the electrical signals generated by sensors into useful information, and this information into electronic commands or visual displays. These functions are achieved through the use of advanced microelectronic devices and sophisticated software algorithms. Advances in these areas are needed to achieve the required signal processing capabilities for a variety of future systems.

Coupled with advanced software and computer capabilities, sensors and signal processing are contributing to the development of "virtual reality" technologies. These technologies can provide a vastly improved, almost life–like environment for simulation and training.

Sensors

There are two general categories of sensors: non–imaging and imaging. Non–imaging sensors are devices that directly monitor physical phenomena. They are used to monitor such parameters as temperature, acceleration, pressure, position, relative humidity, voltage, and current. A variety of materials perform the sensing function in non–imaging sensors. These devices are particularly important in industrial applications. Non–imaging sensors are being used extensively in automotive engine control systems and flexible computer integrated manufacturing.

Imaging sensors play an increasingly prominent role in many high technology applications. These devices detect energy at enough discrete points to create an image of the sensed object. Photodetector arrays, which operate in the visible region of the electromagnetic spectrum, are an important class of imaging sensors. These devices are used in surveillance systems, video cameras, and robot vision systems. One type of X–ray imaging system is used for medical diagnostics and materials analysis. In the infrared spectrum, infrared imagers are instrumental to a range of key applications, including earth monitoring satellites and night vision systems.

Novel materials are integral to the development of a new generation of advanced imaging sensors. While first generation imaging devices were based largely on silicon, advanced imaging sensors increasingly employ compound semiconductor materials like mercury cadmium telluride, indium antimonide, platinum silicide, and gallium arsenide for highly specialized applications. Another important development in sensor technology, particularly for geological and defense applications, is the trend toward multispectral sensing. In multispectral sensing devices, multiple sensors are employed to form a composite image. For example, an infrared image may be overlaid by a radar image to provide a more precise representation of the observed object. As a result multispectral devices provide superior target recognition capabilities.

New fabrication techniques are also playing an important role in improving the capabilities of imaging sensors. Innovative processing techniques have greatly enhanced the resolution of imaging sensors by increasing the number of photosensitive picture elements (pixels) that can be fit on a single device. Another innovation, silicon machining, has permitted the development of new types of miniature sensors that can monitor acceleration, temperature, relative humidity, as well as electrical parameters. Improved processing is also leading to improved photodetector arrays, which in turn improve the capabilities of surveillance, robot vision, and other systems.

Signal Processing

Signal processing, as a generic term, consists of two distinct functions: signal conditioning and signal processing. Signal conditioning involves the "correction" of electrical impulses, or the elimination of spurious signals or "noise." These signals are then converted from a continuous data stream (i.e., analog) to digital form. This step is necessary for the computer to process the data.

In the second stage of signal processing, the processor receives the corrected electrical signals, and then utilizes these signals to deduce the environmental variable (temperature, pressure, electromagnetic energy, etc.). The processor may then make the appropriate response, such as issuing instructions to the system or generating a visual display.

High-performance applications frequently require many sensors to be included in a single system, such as in a phased array. The proliferation of sensors in a single system has increased the importance of validating the reliability of the data acquired by each sensing device: a malfunction in one device can render the entire system inoperable. Efforts are underway to assess trade-offs between redundancy and reliability, and to develop testing strategies for complex systems that do not require the measurement of all possible parameters and that distinguish between system and sensor errors.

Another important issue in signal processing technology is the need for real-time target recognition for the development of "brilliant weapons." Although fully automatic target recognition is not expected in the near-term, existing automatic target cueing (ATC) technologies will benefit defense in areas such as undersea targeting, land-attack standoff weapon guidance, over-the-horizon targeting, airborne multiple-target fire control, anti-ship and other air-to-surface missiles, and assistance in finding relocatable targets. Such applications call for advanced memory and computational capabilities and associated algorithm development.

The trends toward multispectral imaging and improved resolution are placing an ever increasing burden on the sensors' signal processing function. The development of chip-level sensors has led naturally to integrated signal processing, where the signal processing function is incorporated onto the sensor device itself. Integrated signal processing minimizes the need for expensive, bulky, and slow interconnections.

Advanced Human-Computer Interface

Sensors and signal processing are central to the ability of an automated system to interact with its environment. Coupled with advances in software and computational capabilities, advanced sensors and signal processing are helping to revolutionize the interaction between the computer and the human operator. The human-computer interface is becoming more sophisticated and life-like. These advances are leading to the development of "virtual reality" technologies, which could dramatically expand the role of the computer in modern life.

"Virtual reality" technology is a 3-D simulation of an environment that the user can "step into" and interact with. Current systems utilize computerized gloves and a special headset with stereo display. In these systems, the computer creates a "reality" that can be explored, changed, experienced, and shared with others. If the user wants to alter the environment from within, he or she just reaches towards the object to be altered, grasps it, and changes it. The technology is currently being used to a limited extent in architectural design, medicine, aircraft pilot training, and manufacturing. "Virtual reality" technology has dramatic potential as a training tool, as well as in research and development.

Further advances must be made to enhance the quality of human-computer interface to more accurately simulate natural experience. The development of natural language understanding (NLU) would contribute significantly to this objective. NLU systems support efficient and natural human-computer interaction through the use of colloquial speech patterns. Advances in pattern recognition and artificial intelligence may also allow users to communicate with a computer system through speech or handwriting rather than through the use of typed words. Voice recognition would be particularly beneficial in defense applications, as it would allow a pilot to use voice commands to maneuver an aircraft and fire weapons. Handwriting recognition also has important potential; for example, the Internal Revenue Service could employ this capability to process income tax returns rapidly.

REASONS FOR SELECTION

Modern society relies extensively on the ability to develop and control complex, computer-based systems for such applications as manufacturing, transportation, energy, and communications. All computer-based systems require sensors and signal processing to provide the data on which real-time decisions are based.

Advanced sensors are especially important in national security applications. They are fundamental to strategic intelligence functions, providing remarkably accurate eyes and ears at extremely long distances. Tactically, infrared and radar sensors provide U.S. forces with a significant military advantage for operating at night, in all weather conditions, with increasing accuracy at greater and greater distances. Leadership in sensor and signal processing technology is a key to victory in the increasingly automated combat environment.

Commercial applications of advanced sensor and signal processing capabilities are growing. Imaging sensors are the basis for the recent boom in video cameras and camcorders. Advanced sensors are also used in medical imaging, machine vision, space exploration, weather and crop surveillance, oceanography, and high-definition television. Advanced infrared sensors are expected to have an expanding role in transportation applications for night- and all-weather navigation. In the longer term, sensors will form the basis for "intelligent highways" that will address traffic congestion problems. (See ***Intelligent Processing Equipment*** for sensor applications in manufacturing and ***Surface Transportation*** for the use of sensors in intelligent highway design.)

STATUS AND INTERNATIONAL TRENDS

The United States enjoys a strong global position in sensor and signal processing technology. To a considerable extent, U.S. strengths in these areas have been driven by government-funded military and aerospace programs. As in other fields, the United States has experienced difficulty in translating its technological edge in sensors and signal processing into commercial advantage. Moreover, projected declines in U.S. defense spending could jeopardize U.S. technological leadership in this critical area.

While U.S. firms appear to be superior in advanced sensor technology, foreign competition in high-volume, low-cost solid-state sensors is increasingly intense. Foreign firms are showing an impressive ability to bring technologies to market quickly. For example, the Japanese are establishing an advantage in second generation infrared imaging and advanced electro-optical sensors, despite their limited experience in military technologies.

The U.S. has a significant lead over other countries in the area of signal processing technology and in the development and use of complex data bases needed to facilitate signal processing in high-performance applications. Although much of this work is classified, there is much progress underway in NATO countries, Sweden, and Israel, that could contribute to the advancement of signal processing techniques and automatic target recognition applications.

DATA STORAGE AND PERIPHERALS

[Magnetic and Optical Media, and Subsystems]

DESCRIPTION OF TECHNOLOGY

The utility of computers can only be measured by their ability to perform functions more efficiently than some other, less automated, means of problem solving. To be useful, computer systems require an efficient means of entering the data to be processed, some mechanism to view the results of the computer's activity, and some way to store the computations for future reference. Data storage and peripherals provide these ancillary, yet essential, functions. Storage and input/output technologies are required for the full spectrum of computing applications.

Since the invention of the computer, computer scientists have searched for means to store programs and data for later use. Early technologies included paper tape and cards. These rather clumsy technologies were followed by the development of magnetic tape and disk mechanisms. Magnetic media have been the mainstay of the computer revolution thus far, with the more recently developed optical media including compact–disks, read–only–memory (CD ROM), write–once, read–many–times (WORM), and rewritable optical media used as secondary and tertiary (online and archival) storage media for computers now gaining market acceptance.

The same paper tape and cards that provided storage capacity early in the computer era also provided data input. Printers, usually dot matrix type, provided the processed output. These devices, and their successors, are the means by which humans interact with computers. They are used to introduce commands, data, ideas, and images into the computer system for processing, and to receive processed output data and images. This area includes relatively simple items like more user friendly variations of the traditional keyboard, as well as futuristic hardware interfaces like a voice recognition/synthesis system which would allow users to directly communicate with and issue instructions to the computer.

Data Storage

The most widespread current technology for data storage involves magnetic transducers that read and write on magnetic tapes or disks. Such storage systems are sophisticated applications of materials science, tribology (the science of lubrication and wear), and signal processing. Magnetic media provide lower costs per bit than semiconductors and higher data rates than optical subsystems.

Increased computing capabilities have fueled escalating requirements for greater storage capacity and access speed. Several factors are responsible for this trend, including increased program size (due to increased functionality), more demanding applications which generate or process more data, and innovative applications that were infeasible due to data storage limitations, including document retrieval with embedded images and medical applications with images.

Storage technology has essentially three levels. Primary, or semiconductor, memory is the random access memory (RAM) within the computer required for immediate processing needs. This memory must be fast enough to permit the efficient operation of the processor. However, it is extremely expensive to have large quantities of semiconductor memory. Secondary memory in the form of disk storage is less expensive, but also slower than RAM, so it is used to store data or applications that are not needed for the internal functioning of the computer. This is generally called mass storage, and has 10 to 50 times the semiconductor memory capacity. Finally, tertiary storage is needed for the maintenance of archival data, where it can be kept offline and referred to when needed. Archival storage is least expensive and slowest in response time, but is cost–effective for long–term storage of the copious quantities of output from the computer. This level of storage frequently has a capacity of 10 to 50 times greater than mass storage.

The most demanding applications for data storage are usually associated with high-performance computers or "supercomputers." Without the large, low-cost capacities provided by tertiary storage, high-performance computing would be impractical. Mainframe computers at major Federal agencies produce archival information requiring hundreds of thousands of magnetic tape reels and cartridges.

Measures of performance are used to both characterize specific media and compare different media and subsystems. Density of information storage on the media, access time, and data transfer rates are generic measures of the capacity of media and responsiveness of storage systems.

Compact disks are a familiar form of optical disk technology first used in audio applications. Mass production is done from masters by physically impressing the information onto the surface of the disk. Data are recorded in a helical spiral as impression pits etched by lasers in a surface cover, or phase changes in a reflective material. These data subsequently are read by detecting changes in reflected light from a laser source.

Peripherals

The general term "peripherals" includes all forms of input and output hardware. Current input devices consist of keyboards, mice/trackballs, light pens, digitizing tablets, video cameras, and text/image scanners. Newer input technologies under development include handwriting pens and tablets and voice recognition systems. Output devices in general use include printers (daisy wheel, dot matrix, laser, electrostatic, and other high-speed devices), plotters, CRTs, movie and/or video cameras/recorders, and facsimile machines. Newer output technologies include voice and music synthesizers and 3-D imaging devices.

In addition to these input/output devices, this area of technology includes the software that enables the initial interpretation and recognition of the input information, and also controls the formatting of the output information. Although this software has in the past been generally considered as part of the "main" computer program, considerable performance increases are possible when the hardware input device and its associated control/interpretation software are bundled into a package, along with a combining of the output hardware and its software. These developments free the main processor from the requirement to perform the input/output processing, thus increasing overall performance.

Peripheral devices are often thought of as unitary technologies -- printers print. In reality, however, they are composed of a number of divergent hardware and software technologies. Text/image scanners, for example, utilize three component technologies: sensing, electronics, and paper handling. As the hardcopy document passes the sensor, the arrangement of image content is detected and converted to electronic signals. Electronic processing often "corrects" irregularities in the data received from the sensors. Intelligent character recognition techniques may further process the image data and produce encoded textual data and document layout. Finally, paper handling technologies are needed to deal with any significant volume or variation of input documents.

Printers also utilize three major component technologies: marking, electronics, and finishing. The marking technology causes electronic signals to be rendered in some visible fashion, such as ink drops or toner particles adhering to specific locations on a piece of paper. The software running in these computers must control the various imaging elements, such as lasers and paper motion, and increasingly can render the full range of document content through paper description languages. The simplest finishing technology is a stacker tray that receives the printed pages. More complex finishing provides stapling, binding, folding, inserting, cutting, and trimming options.

REASONS FOR SELECTION

Storage technology is a limiting factor in the application of other information technologies. Development of high-performance computing applications is dependent upon vast storage capacities. Such applications include modeling and forecasting weather, modeling global change, mapping the human genome, and design of high-performance aircraft. Archiving and management of data collected from satellites are already overwhelming existing storage facilities. Multi-media workstations, which are currently being developed, will store and process text, images, and voice and will require significantly larger secondary storage subsystems.

Input/output technologies, such as printing and voice recognition, are critical in that they improve the user's ability to utilize computing capabilities. These technologies increase the cost-effectiveness of computers by reducing the difference between the way in which humans normally interact and the way in which data and instructions are moved into and out of computers. Without some sort of input/output devices, the most advanced computer is worthless. Additionally, the ease of use of input/output devices represents in large part the perception humans have of the computer and its utility.

STATUS AND INTERNATIONAL TRENDS

The storage system industry is a $50 billion industry, in which the United States enjoys a strong leadership position. For example, the disk drive was developed and brought to commercial introduction by IBM. However, the U.S. position is now at risk as the large Japanese computer companies are all developing high capacity storage systems. While performance improvements in capacity and throughput are expected for both magnetic and optical media, additional research and development are required.

Thin film recording head transducers and recording media are current topics of magnetic media research. Thin film transducers and thin film media promise to improve performance by at least an order of magnitude. A goal of the research is to develop prototype 3.5 inch disk drives capable of storing 1- gigabyte of data within five years — a 25 fold increase over today's technology. Recently, redundant inexpensive disk arrays have been developed based upon 5.25 inch rigid disk technology. While promising to reduce data loss and reduce floor space required for large storage subsystems, the technology has not been widely deployed.

In recent developments, data formats for optical media have been developed which are comparable to those used for magnetic disks and significantly improve access time. Holographic optical elements are being explored to replace glass lens and supporting structures to reduce weight and improve access time of the read head in optical systems. Current read and write storage systems have data record speeds which are limited by the power of available semiconductor lasers.

Widespread acceptance of optical media has been slowed by the lack of interchange standards and by limited information on the life expectancy of data stored on the media. Unlike magnetic tape for mainframe computers, where media standards have encouraged multiple vendors to produce interchangeable media and drives, the optical media industry has produced a variety of data formats for otherwise quite similar media. Consequently, users are not confident that, at some later date, consumers will be able to obtain optical disk drives to read data written today. Furthermore, while magnetic storage has a relatively limited lifetime of about 10 years as an archival medium, similar quantifiable experience is not yet available for optical media.

As limits to storage densities and data transfer rates are reached and massively parallel computers become common products, architectures and products for highly parallel disk storage subsystems will be required. While they are likely to be fabricated out of rigid magnetic disk media, architectures for controllers, data storage and management, and supporting operating system components are likely to be substantially different.

The United States and Japan are the major innovators in printing technologies. In the low-end market segment, consisting largely of dot matrix printers common on personal computers and facsimile machines, Japanese capabilities in electromechanical systems and designing for producibility have resulted in a very strong market penetration. The mid-range market segment includes laser printers with speeds between 10 and 40 pages per minute. Traditional U.S. strengths in leading edge technologies and integration have given domestic firms a market lead in laser printers.

These printers, however, use foreign-made printing engines with the U.S. value-added being the integration of the technologies and proprietary software. The high-end market segment includes systems with speeds that exceed 50 pages per minute with high-quality resolution of 600 spots per inch. In this sector, U.S. strengths have given domestic firms a significant but not necessarily permanent market dominance.

COMPUTER SIMULATION AND MODELING

DESCRIPTION OF TECHNOLOGY

Simulation and modeling systems are computer-based tools that allow scientists, engineers, and operators to test complete systems, advanced structures, design concepts, and command methodologies under a variety of conditions. With specially designed software and computer hardware, advanced simulation and modeling techniques will allow researchers to create and utilize virtual reality with an unprecedented degree of control and realism. Simulation and modeling can be applied to almost any situation that would otherwise require laborious physical testing or which may be impractical or impossible to test directly. The following highlights the diversity of simulation and modeling applications and the ways in which these techniques can be applied to the solution of complex problems.

Defense

The military sector currently uses simulation and modeling techniques for a large number of applications, including simulation of combat operations (from small-scale tactical levels to global combat), simulation of complex system performance, and training. As an example, DARPA's Simulation Network (SIMNET) is a large-scale simulation environment for combat training of tank platoons and helicopters. In addition, the SIMNET environment can be used to "prototype" new weapons systems without the need to construct a working model.

Over recent years, enhanced graphics and data bases have been essential in improving the quality of simulation and modeling technology for defense purposes. For example, advances in three areas are converging to support flight simulation systems for training and cockpit resource management. Technologies that will boost success in the field are:

- **Visual systems**, which include image generation and display and depend upon improvements in field-of-view capabilities and realistic detail
- **Distributed processing techniques**, which are applied to the entire simulator operation and serve to enhance the visual systems
- **Instructor station capabilities**, which simplify an instructor's task, allow more time for management of simulation exercises, and apply artificial intelligence techniques to produce advancements in interactive systems such as touchscreen inputs.

Manufacturing

Simulation and modeling is currently used by some commercial and defense firms to save time and money in many aspects of manufacturing and eventually is expected to become pervasive in small and large firms across all manufacturing sectors. Simulating design, manufacturing, and testing processes on a computer minimizes waste in materials, allows for processes to be refined or altered, and improves the rate at which products are brought to market. Today's computers can handle more complex simulation programs than ever before. In the next ten years, with widespread implementation of computer integrated manufacturing (CIM), simulation and modeling advances will be the driver in implementing more efficient manufacturing approaches.

These techniques will also be used more frequently to design and optimize the performance of traditional processes, including forming, casting, forging, powder consolidation, and welding, and to perform general applications with shorter trial and error periods. For example, future applications for simulation and modeling software include systems that will allow engineers to visualize machining processes in advance. This type, called numerical control (NC) simulation, reduces cost, time, and paperwork involved in processing a raw material into a part. The simulation model depicts on a computer screen the paths that machine tools follow to mill, turn, drill, bore, punch, and otherwise sculpt parts, allowing manufacturing engineers to detect process defects in a timely manner. By having the capability to measure and assess many different options before cutting raw material, material waste and cost are kept to a minimum.

In another manufacturing application, simulation and modeling is being used to improve the operation of production lines and reduce the requirement for buffers (extra stocks of materials or parts) by as much as 25 percent. Buffers prevent a production line from shutting down when a problem occurs, but are also capital intensive and take up storage space. Also, to encourage greater use of simulation and modeling on the factory floor, software producers have developed user-friendly packages to minimize the programming required. Although many manufacturing-oriented programs are currently tailored for specific purposes (such as materials handling), friendlier and more general-purpose systems will be realized in the future. Companies also use simulation and modeling techniques to analyze administrative problems such as capital investment and staffing policies.

Agriculture and Medicine

Simulation and modeling is enjoying rapidly growing applications in agriculture. By helping to assure that just the needed quantities of agricultural chemicals are applied at exactly the right time, excesses that lead to surface and groundwater pollution can be avoided. Farmers are rapidly becoming aware of the benefits of this technology and are gaining access to the necessary hardware and software. As an illustration, a decision support system based on a physiological model of the cotton plant has allowed farmers to increase profits by approximately $50 per acre. Moreover, simulation and modeling programs that help to boost food production are of strategic importance for international trade.

Plant and soil scientists have for many years used computer models as research tools to study plant-environment, plant-nutrient, and plant-pest interactions as well as cultivation-erosion relationships. More recently, such models have been equipped with inference interfaces and utilized in decision support systems to ensure that information from all relevant disciplines and data from all available sources are integrated to improve agricultural management.

Useful applications of simulation and modeling to the highly complex and organized systems of cells have had to await access to high-performance computers and the development of appropriate software. Increasingly, simulation and modeling is being employed to elucidate biological processes, to study the structure and dynamics of proteins and other macromolecules in solution, and in the design of molecules with specific receptor affinities. Such usage is likely to multiply rapidly.

Computational Fluid Dynamics

Computational fluid dynamics (CFD) is a specific software application that has been used in many industries to develop products dependent on the science of fluid flow. By predicting fields of pressure, temperature, velocity, and turbulence in and around objects, CFD can determine the best shape and size of equipment, as well as the properties of fluids and related materials. This tool can take the place of initial testing for missiles and aircraft and can be used to predict the effects of aerodynamic processes. There are numerous commercial and defense applications involving problems in which air is the fluid being tested, including simulation of flight and gas turbine engine operations. Manufacturing applications that require fluid flow analyses include processes such as chemical vapor deposition and plasma spraying.

In the commercial sector, CFD is expected to be used with greater ease and frequency in the automobile industry. In addition to modeling, computing stresses, and controlling machines, CFD can aid in the testing of external and in-cylinder flows. Also, this technology is used for simulations of passenger-compartment air flow, oil flow and cooling, fuel-air mixture preparation, spark ignition, tire adhesion, metal forming, and paint application.

Prediction of Weather, Climate, and Global Change

Another rapidly developing application of computer simulation and modeling is in operational weather forecasting, study of local and regional (mesoscale) weather systems, and prediction of climate change. Operational global models are used for medium-range forecasting in the 3-to 10-day range for aviation and marine purposes. The emphasis in these models is on integrating weather over large areas of the globe. On the other hand, limited-area or regional models are used for short-range predictions extending 1 to 2 days and focused in greater detail on the areas of primary interest. The ability to model and predict local severe weather conditions, with adequate warning time for the population, has particularly important economic and societal benefits. Historically, problems requiring computer modeling of atmospheric circulations on continental, hemispheric, and global scales have provided a major impetus to developments in computer software and hardware.

Recent concerns over global climate change have led to the development of large-scale computer models that take into account interactions of the various components of the biogeochemical, hydrological, vegetation, and physical-climate systems. These models are designed to simulate some of the important processes of global change, such as the direct response of the climate system to increased atmospheric concentrations of carbon dioxide and other so-called "greenhouse" gases. One type of climate prediction model tries to estimate future change based on reconstructions of past climates. The other type, known as a general circulation model (GCM), is derived from weather forecasting models and includes representations of other elements of the climate system such as oceans and land surfaces. Improving the quality of these models involves a substantial ongoing international effort in data gathering and management, model development, documentation, testing, application, and verification.

REASONS FOR SELECTION

Simulation and modeling has become integral to development and implementation of new technologies in such diverse areas as defense, manufacturing, agriculture, and medicine. While the wide array of applications described above attests to the important role that simulation and modeling has already assumed, future applications are limited only by the creativity of the software designer and the depth of analysis brought to bear by the user. Although there are current applications in complex systems, manufacturing and production, CFD, finance, environmental "mimicking," and biotechnology design, future success in this technology will depend on perfecting and advancing existing techniques. In the next ten to fifteen years, the goals of scientists and engineers are to reduce design costs, increase flexibility, and optimize design by anticipating changes in performance, thus reducing needless trial and error.

Increasingly, simulation and modeling is shown to be not only the best way of attaining an objective — it is often the only way. Integrated complexes, sometimes referred to as "systems of systems," characterize modern military and civilian operations. Increasingly, these systems are too complex to be built and managed using traditional manual and computer-based techniques. Examples include the operation of an aircraft carrier battle group, of a strategic missile defense system, or of the North American air traffic control system. The command, control, operation, design, and testing of such integrated complex systems of systems is possible only through advanced simulation and modeling. For example the Navy's Aegis system employed a complete simulation (known as "the frigate in the corn field") throughout its development; this system has been replicated for training. The SIMNET system has demonstrated its worth in integrating crews and troops at widespread locations into a single computer-simulated battle. The Strategic Defense Initiative National Test Bed is the most recent and complete example, utilizing two supercomputers in its new facility to test strategic defense concepts and hardware, which cannot be adequately tested in an operational environment.

STATUS AND INTERNATIONAL TRENDS

Simulation and modeling techniques were first developed in the United States at the time of the Manhattan Project. As scientists developed advanced technologies for warfare, the development of simulation and modeling techniques to test for climate changes and to produce weapons became critical. As the technology matured, U.S. simulation and modeling capabilities expanded to other industries and applications. Because of the scale of resources required, comprehensive simulations are likely to continue to be dominated by applications for large systems (as in aerodynamic design, modeling water supply, or war gaming).

The challenges in this technology are in software design and computer hardware. The United States has maintained a strong position in software but is losing its edge in certain areas to the Japanese, Europeans, and third world nations. The computer industry is also becoming increasingly competitive. Because simulation and modeling is dependent upon a high degree of sophistication in creating reality on a computer, advancements in computer capabilities and architectures that lead to more adaptable and accurate graphic and pictorial models are necessary for the technology's future success.

Military and civilian simulations have also been developed and used by other countries, especially European. The Japanese have developed excellent capabilities in simulation and modeling techniques for massively parallel computers and are currently organizing a national effort to collaborate on this type of software application.

BIOTECHNOLOGY AND LIFE SCIENCES

- Applied Molecular Biology
- Medical Technology

BIOTECHNOLOGY AND LIFE SCIENCES

The life sciences demonstrate, perhaps more vividly than any other discipline, the synergy between scientific discovery and the commercialization of innovative and life–enhancing products. The publication by Watson and Crick in 1953 of their startling hypothesis that the genetic basis of life resides in a so–called "double helix" of DNA strands stimulated intense scientific effort to understand the cellular and molecular basis of biological processes. These advances have led to the development of recombinant DNA techniques, monoclonal antibody technology, sophisticated new approaches to bioprocessing, and other biotechnological applications with almost limitless potential to benefit mankind.

The "new" biology is having a profound impact on health care. Already, it has spawned scores of important new products and approaches for the prevention, diagnosis, and treatment of disease. In addition, applied molecular biology has important potential for many promising applications in energy conservation, bioremediation of wastes, production of chemicals for a variety of uses, and other industrial processes. Recombinant DNA technology and other biotechnological techniques also hold considerable promise for improving the performance of agricultural crops and enhancing the productivity of livestock.

The revolution in applied molecular biology has been accompanied by dramatic advances in the development of sophisticated medical technologies, which increasingly play a vital role in disease diagnosis and intervention. These technologies—derived largely from the physical and computer sciences—include laser technology, magnetic resonance imaging, positron emission tomography, advanced biosensors, and biocompatible prostheses. These technologies are contributing to longer life spans and improved quality of life.

Future progress in advanced medical technology and applied molecular biology is likely to be stimulated by growing demand for advanced medical services as a result of population aging of many industrialized countries, and increased requirements for environmentally benign industrial processes and agricultural methods. However, the future impact of these technologies is also likely to depend on other external factors including the regulatory environment, public acceptance of products generated through biotechnology, and increased public concern regarding rising health care costs. These and other such issues must be resolved to realize the full benefits of the rapid pace of technological progress in biotechnology and the life sciences.

APPLIED MOLECULAR BIOLOGY

DESCRIPTION OF TECHNOLOGY

Spectacular advances in the understanding of the molecular basis for cellular functions are the foundation of a new biology with almost limitless potential for the betterment of mankind. The basic techniques used to harness this scientific knowledge for practical purposes are known collectively as applied molecular biology, or biotechnology.

According to the Office of Technology Assessment, biotechnology consists of "those techniques that use live organisms (or parts of organisms) to modify products, to improve plants or animals, or develop microorganisms for specific uses." Biological processes have been employed for thousands of years in such uses as fermentation (an essential step in baking bread and brewing beer). However, this technology category refers primarily to new and innovative techniques to modify or to manipulate biological organisms to produce useful products. These capabilities are bringing about a revolution in the development of new vaccines, therapeutics, agricultural products, specialty chemicals, pollution control mechanisms, and materials.

The basic tools of applied molecular biology include recombinant DNA technology, protein engineering, monoclonal antibody production, and bioprocessing. The following discussion describes these techniques and discusses their potential implications.

Recombinant DNA

Recombinant DNA techniques (also known as genetic engineering) most frequently involve the transfer of genetic material between differing organisms. This transplanted genetic material contains encoded instructions for functions characteristic of the original cell, namely the production of vital proteins. The transplanted gene imparts that function to its new host cell.

Recombinant DNA technology is frequently used to introduce a target gene into cells that can be grown in culture. The transplanted gene replicates as the new host cells divide. In this manner, for instance, a desired protein can be produced in large quantities, harvested from the culture fluid, purified, and prepared in bulk. By introducing human genes into cultures of bacterial, yeast, or mammalian cells, biotechnology companies have succeeded in developing commercial quantities of a new generation of important preventive and therapeutic proteins, including vaccines, human insulin, human growth hormone, cancer-fighting agents, and drugs that dissolve blood clots and treat anemia.

Recombinant DNA technology also appears applicable to the treatment of some genetic diseases in humans through the introduction of normal genes into a patient's cells. This new field of gene therapy potentially could eliminate or ameliorate many forms of inherited diseases. Likewise, genetic material has been directly introduced into animal embryos, thereby creating "transgenic animals" which exhibit the traits associated with the foreign gene. Transgenic mice, with defective human genes, for example, have an important potential as models of human disease.

While the initial impact of genetic engineering has been most apparent in the field of human health, these techniques also have the potential to make a major contribution to agriculture. New traits may be transferred to transgenic plants, such as improved pest, drought, and disease resistance. Transgenic livestock may be developed that are leaner and can be raised more efficiently. Safe microbial pesticides developed with recombinant DNA technology could replace some chemical pesticides.

Cultures of genetically-modified cells can also be employed in the production of specialty and bulk chemicals, including enzymes and other biochemical products used in food processing. Receptors from nerve and muscle cells are being cloned to be used as sensors to detect toxic chemicals in the workplace or water supply. The tools of recombinant DNA technology are also being used in the development of materials as varied as antifouling paints, high energy cathodes, and high-strength, lightweight composites.

Recombinant DNA and other techniques of molecular biology can also be used to identify the location of a specific gene on a particular chromosome. A collaborative international program has recently been launched to develop a comprehensive "map" of the human genome. Such a map will assist researchers in investigating the function of specific genes and could lead to effective gene therapies to correct defective genes as well as a better understanding of normal physiological processes. To date, researchers have succeeded in isolating and identifying only a small portion of the 50,000 to 100,000 genes present in every human cell. A major contribution to this effort is provided by the new polymerase chain reaction techniques which greatly amplify DNA and so increase the amount of genetic material available for study. The development of similar types of genome maps for major agricultural crop plants would be an important tool for harnessing biotechnology to improve crop production.

Protein Engineering

Protein engineering embraces systematic, analytical approaches for the development of useful proteins for specific applications by altering their molecular structure. This procedure already is employed in a number of important industrial applications. By combining selected portions of various molecules, researchers have developed novel enzymes that can catalyze reactions in solvents other than water, or which are capable of synthesizing industrial chemicals more efficiently than conventional methods. Proteins have been modified to increase their stability in a variety of environments, making possible new food production methods, better laundry detergents, and biochemicals for destroying wastes.

Similar techniques have important potential for the development of new therapeutics. The cell's defenses against infection as well as other vital cellular functions are activated when a protein molecule with an appropriate shape binds to a "receptor" on the cell membrane. Using the tools of biotechnology and sophisticated analytic methods, researchers can design highly specialized binding molecules -- or "biological response modifiers" (BRMs) -- to trigger the desired cellular reaction. This development of new therapeutics, based on a detailed understanding of protein shape and the molecular basis of cellular functions, is known as "rational drug design." While "rationally designed" drugs have not yet appeared in the marketplace, these techniques have the potential to revolutionize the development of more effective therapeutics.

Monoclonal Antibody Production

Monoclonal antibody technology has already begun to alter medical practice. Monoclonal antibodies are produced by combining antibody-producing, disease-fighting white blood cells (lymphocytes) with tumor cells which divide continuously to create a culture of hybrid cells that can produce large amounts of homogeneous antibodies. Because the antibodies resulting from this procedure are cloned from a single hybrid cell, they are known as "monoclonal" antibodies. As a result, these antibodies are highly specialized and only attack a specific disease-causing agent or cell type.

The development of monoclonal antibodies has spawned scores of new diagnostic products which are used to detect sexually-transmitted diseases including HIV infection, as well as cystic fibrosis, hepatitis B, various forms of cancer, and other disorders. Monoclonal antibodies may also be employed in the development of highly specific and sensitive detection systems for plant and animal diseases, as well as food-borne pathogens. Monoclonal antibody technology may also have important therapeutic applications in addition to its current use for disease diagnosis. For example, researchers are developing tumor-seeking monoclonal antibodies which can carry anti-cancer agents directly to the cancer cells. Thus, very high concentrations of drug can be achieved without causing significant harm to healthy cells. Recent developments have led to the production of monoclonal antibodies with enzymatic activity. These have considerable medical and industrial potential.

Bioprocessing

Bioprocessing is the critical link between the basic science of biotechnology and the production of therapeutic drugs and other life-enhancing products, food enzymes and ingredients, and specialty products for agriculture and industry. Bioprocessing is potentially more energy efficient, product specific, and environmentally clean than conventional organic synthesis. Opportunities for genuine innovation are abundant. However, the economics of bioprocessing must be improved for biotechnology to achieve its full potential.

Novel techniques have been developed to allow bioprocessing on a commercial scale. Microbial, plant, and animal cells have been genetically modified to increase their production of desired biochemicals. Some cell types have been tailored to secrete the product into the culture broth rather than to retain it within the cell wall--a method which simplifies purification. The productivity of cell bioreactors is being improved with the development of packed or fluidized beds, micro-carriers, and hollow-fiber technology. Enzymes that have been immobilized on membranes are facilitating product removal. Advanced affinity and chromatography techniques and membrane filtration technologies are boosting the efficiency of product purification.

REASONS FOR SELECTION

The potential applications of molecular biology span a broad spectrum of the U.S. economy. For some sectors, such as disease prevention and treatment, this potential has become a reality. In others, further efforts must be made to transform what is technically possible into commercially viable applications. The most promising areas for future progress are in the fields of human health, agriculture, energy conservation, specialty chemicals, new materials, and bioremediation.

In the health field, the tools of applied molecular biology offer considerable potential for understanding, diagnosing, preventing, and treating a wide range of disorders, including hereditary diseases, AIDS, and cancer. Gene therapy has the potential to cure or ameliorate many hereditary diseases and disorders such as cystic fibrosis, muscular dystrophy, sickle cell anemia, and Huntington's disease. Other tools of applied molecular biology, such as the development of transgenic animals, also may be instrumental in the development of effective treatments for AIDS, cancer, and other diseases.

In agriculture, biotechnology has the potential for improving the efficiency of livestock. A biotechnologically-produced hormone that promotes the growth of healthier, leaner pigs is under development. Biotechnology also has the potential to increase crop yields, improve crop quality, and reduce production costs while minimizing the detrimental environmental impacts of pesticides and chemical fertilizers. A number of innovative products of agricultural biotechnology are nearing the market, such as environmentally safe biopesticides and disease-resistant crops. Such products represent the leading edge of a technological revolution in agriculture.

Bioprocesses are also being harnessed to fabricate novel materials, such as spider silk and underwater adhesives (from mussel cell cultures) for commercial applications. Other biological polymers are being developed to produce high-strength, elastic materials. The new biology has also made possible the development of biosensors, which have important applications in ultrasensitive detection systems for medical diagnostics, pollution control, detection of explosives and illegal narcotics, and industrial process control.

Genetic engineering has become an important new tool in environmental protection by making possible the development of microorganisms that efficiently degrade solid wastes and toxic chemicals, clean up oil spills, and assist in the treatment of wastewater. These techniques may also be useful for developing microbes that produce enzymes useful for converting biomass, a potentially important source of renewable energy. Other genetically-engineered microbes which are capable of extracting minerals are also being investigated.

Technological progress in bioprocessing is key to realizing the full potential of biotechnology. Bioprocesses are being explored for the manufacture of chemicals used in pharmaceuticals, cosmetics, household products, and industrial production. Recombinant DNA technology is well-suited for the large-scale synthesis of natural biological products like peptides, enzymes, and vitamins. Other organic chemicals may also be produced efficiently using bioprocesses.

STATUS AND INTERNATIONAL TRENDS

At present, the United States enjoys leadership in the research base for applied molecular biology. The field has benefited from the strong financial support of the Federal government; an excellent research base in leading universities, the National Institutes of Health, and the Agricultural Research Service; a high level of collaboration between industry and the university research community; and a dedicated, entrepreneurial workforce. A world-class pharmaceutical industry and strong agricultural sector also contribute to an excellent infrastructure for biotechnology research and product development.

In bioprocessing, the United States has a clear advantage in harnessing the tools of applied molecular biology in the medical area. Other areas of promise have received significantly less attention. Government R&D programs have emphasized applications to human health; private investors in biotechnology have also viewed therapeutics and diagnostics as the most attractive areas for investment. Nonmedical applications like agriculture, alternative fuels, new materials, specialty chemicals, and pollution control also have great commercial and technological potential, but have only begun to be exploited.

A number of European countries have the scientific potential to become strong competitors with the United States in biotechnology, particularly in the field of diagnostic, preventive, and curative products for human health. Germany, for example, has strong pharmaceutical companies. Its research base is first-rate, and the government is devoting substantial R&D resources to the field. However, inadequate venture capital markets and regulatory obstacles to establishing new biotechnology businesses may inhibit Germany from fully capitalizing on its strengths. The United States offers a relatively positive environment for biotechnology start-up firms, but time-consuming product approval processes, delays in securing patents, and deficiencies of venture capital remain significant constraints to the development of the U.S. biotechnology industry.

Japan is devoting considerable public and private resources to improve its capabilities in biotechnology. The Japanese emphasis on the development of nonmedical applications is evident in food products, waste management technology, and biochemicals. Japan's extensive experience in bioprocessing and fermentation technology allows it to capitalize rapidly on research developments elsewhere in the world. The field of biosensor technology is rapidly expanding, with increasing numbers of publications and patents appearing each year. Several Japanese companies have already begun to sell devices for environmental monitoring, industrial analysis, and clinical analysis which utilize miniaturized electrode technology. Of the present commercially available instruments, 15% are of American origin; virtually all the others are Japanese. Japan is moving to improve its research base in molecular biology, but in the meantime, Japan is noted for the speed with which it can translate scientific knowledge generated anywhere in the world into commercial advantage.

MEDICAL TECHNOLOGY

DESCRIPTION OF TECHNOLOGY

Innovative medical technology has revolutionized American medicine. Medical technology encompasses many diverse areas of science, drawing on advances in computers, fiber optics, materials science, electronics, lasers, sonography, and other fields. Medical products include new diagnostic imaging equipment that can provide precise pictures of bones, organs, tissue, and neural activity; implanted devices such as cardiac pacemakers, defibrillators, artificial heart valves, and hip replacements; and innovative noninvasive alternatives to conventional surgery, such as lithotripsy, a technique using shock waves to crush kidney stones. Indeed, the medical technology industry is characterized by a dynamic pace of innovation and rapid diffusion into the medical marketplace. This discussion focuses on medical products and equipment, other than drugs, used for the diagnosis, mitigation, or treatment of disease.

Several areas illustrate the rapid rate of progress in the field. In less than two decades, we have moved from conventional X–rays to a host of advances in imaging technologies. The CAT (computer–aided tomography) scan uses computer technology to reconstruct multiple X–rays into a three–dimensional "slice" of the patient's body. Subsequent product improvements have increased the intensity, quality, and speed of the equipment. Magnetic resonance imaging (MRI) uses the interactions of hydrogen atoms in human tissues with magnetic and radiofrequency fields to produce images of tissue and organ structures. Advances in MRI include angiography (MRA), which transforms electrical signals into computer images that provide accurate data on the vasculature of the brain. Spectroscopy (MRS) generates spectra that reveal identities and levels of various metabolites in the body, allowing, for example, assessment of heart attack or stroke. The positron emission tomography (PET) scan measures glucose metabolism of neural tissue. Following injections of radioactive glucose, the scanner can map areas of brain activity. These relatively noninvasive technologies have opened the door to early detection and effective treatment of a broad range of life–threatening conditions.

Major advances are also occurring in implant technology. Cardiac pacemaker development illustrates the dynamic pace of innovation. From large, cumbersome devices driven by external power sources, state–of–the–art pacemakers are now miniaturized (from the size of hockey pucks to half dollars), fully implantable, and rate–responsive to individual cardiac rhythms. There are also important advances in implant materials. For example, researchers have tailored biodegradable polymer microcapsules that slowly release proteins to encourage bone growth following dental or facial surgery. A family of nontoxic polymers has been developed that creates biodegradable structures with microencapsulated growth hormone to stimulate bone growth.

Breakthrough technologies offer alternatives to conventional surgery. Lasers are proving superior to traditional techniques by causing less bleeding, fewer complications, and faster healing. Lasers offer a growing number of medical applications; they can resculpt the shape of corneas, remove cataracts, and vaporize plaque deposits in coronary arteries. Fiber optic technology has expanded the use of angioplasty and arthroscopic surgical techniques. First generation lithotripsy uses sound waves to crush kidney stones without surgery. Newer lithotripters employ optical fibers with pulses of laser light that pulverize the stones.

Sensors are an important development in diagnostics. They combine electronic circuits with biological material. In an at–home glucose monitoring system, a drop of blood is placed on the tip of a detector containing glucose oxidase bound to flavin adenine dinucleotide (FAD). The glucose from the blood binds to the strip, releasing electrons. By counting electrons, the device can provide immediate and accurate test results. There are numerous other potential applications of this technology that will vastly improve a wide range of diagnostic procedures.

REASONS FOR SELECTION

Innovative medical technology can enhance the quality of life and ease suffering from disease and disability. Due to the aging of the population and the demand for products that improve and prolong life, major global market growth is expected. The United States has long dominated the global marketplace for medical technology. The U.S. consumes over 40% of all medical technology produced worldwide, and has consistently maintained a trade surplus in the industry ($3.2 billion in 1990). The industry is very research–intensive and has demonstrated leadership in development and commercialization of breakthrough technologies. High technology medical equipment is also vital to national security. Sophisticated and responsive emergency treatment capabilities are essential in times of war.

STATUS AND INTERNATIONAL TRENDS

The United States cannot afford to be complacent despite its present strength in medical technology. The cost–insensitive health care environment of the past has given way to intense concern over rising costs (health care expenditures account for more than 12% of GNP). Medical technology is often blamed for cost increases, although many technologies may actually reduce costs by reducing the length of hospital stays. Frustrated by seemingly intractable cost problems, and hampered by lack of good data about the link between technology and actual expenditures, many see medical technology as a mixed blessing. Also, because the government is deeply involved in its role as payer (Medicare outlays alone were over $107 billion in 1990), policymakers have focused on controlling market growth rather than promoting competition in this dynamic industry. This increasingly cost–conscious marketplace, along with regulatory constraints, product liability threats, and the present economic slowdown, may discourage innovation and product development in the future.

As the American market stabilizes, producers will increasingly have to look to foreign markets for new opportunities. However, sophisticated medical technology requires a well–developed medical infrastructure, limiting markets for certain products to developed nations. Most of these nations are also struggling to control rising health care costs and deal with complex regulatory regimes and government–controlled pricing policies.

There are signs that America's competitors are gaining ground. The United States has a negative balance of trade in medical technology with Germany. While the overall U.S. balance of trade in medical technology with Japan is still positive, the United States is now a net importer of Japanese electromedical equipment such as imaging devices. Over half of the technologies identified as highest priority emerging technologies by the Japan Science and Technology Agency were medical and biotechnologies. Thus, competition in both developed and developing nations abroad will be fierce, and only the most cost–effective, highest quality products will succeed.

AERONAUTICS AND SURFACE TRANSPORTATION

- Aeronautics
- Surface Transportation Technologies

AERONAUTICS AND SURFACE TRANSPORTATION

This section includes two applications–oriented areas where continued advances in technology and technology management will have a critical impact on the competitiveness of U.S. industry, the balance of trade, military strength, and the quality of life. Aeronautics is a traditional area of U.S. strength; the U.S. aircraft industry has led the world in military and civilian aircraft performance, production, and export sales.

Aeronautics encompasses a broad range of technologies, many of which are National Critical Technologies in their own right. These include: propulsion (which itself represents a complex integrated set of technologies), materials, electronics, and the capability to integrate complex technologies into a system. Future generations of high–performance aircraft depend on substantial advances in all of these underlying technologies.

While the United States maintains an overall edge in aeronautics, the lead has substantially narrowed in many of the underlying technologies. The Europeans and Japanese have made substantial gains in selected electronics and materials technologies, and the Europeans are competitive with U.S. producers in civil air transport export markets. The United States is maintaining its overall strength in systems integration.

Advanced surface transportation technologies can relieve growing congestion on U.S. highways, improve vehicular safety and fuel efficiency, reduce reliance on liquid fuels, provide more affordable mass transit, and reduce air pollution. Promising technology applications include intelligent vehicle/highway systems and compact power sources. Technical challenges that must be overcome before these can become technically feasible and affordable include continuing advances in electronics, sensors, information technologies, materials, and compact power sources.

AERONAUTICS

DESCRIPTION OF TECHNOLOGY

Aeronautics encompasses an array of technologies essential to the design, development, construction, testing and qualification, operation, performance, safety, and flight management of aircraft. Although these technologies are inherent in all classes of aircraft, the focus of this section is on the key technologies associated with the larger and more advanced aircraft, such as large subsonic transports, high-performance military aircraft (both fixed and rotary wing), and supersonic and hypersonic aircraft. Leadership in these aeronautical technologies will be a necessary condition for leadership in the commercial aviation marketplace and for military air superiority in the next century.

Propulsion

Turbine and turboprop engines propel all large transports and military aircraft, and are a key determinant of aircraft speed, range, noise, agility, and payload. More powerful engines, with better fuel economy and significantly lower levels of nitrous oxide emissions, are required for the next generation of commercial aircraft. High-thrust turbine engines with the ability for sustained supersonic cruise without afterburners and having low thermal signatures will be necessary for many military aircraft. Specific areas which need priority attention are: highly integrated engine/airframe designs; ultra-high bypass, variable cycle, multi-fuel, and hybrid (e.g., air turbo-ramjet) engines; advanced engine components (inlets, propellers, fans, compressors, combustors, nozzles, etc.); and advanced aerothermodynamics and aerothermochemistry (to improve engine performance).

Aviation Materials and Structures

Aviation materials and structures must meet increasingly demanding requirements for strength, durability, rigidity, temperature and corrosion resistance, size, weight, and (for military purposes) "stealth." Advances in materials enable improvements in airframes and aircraft engines. Specific materials areas which require additional emphasis are advanced polymers, metals, intermetallics, ceramics, fibers and composites, and the technology to create them in economic quantities. Specific structures areas which demand attention are: advanced structures theory and computational structural mechanics; hot structures and actively-cooled structures for hypersonic aircraft such as the National Aero Space Plane; and new inspection, life prediction, corrosion control, and repair methods to extend the useful life of aging aircraft.

Aerodynamics

Aerodynamics involves the complex physical laws, theories, and computations that underlie the design and performance of aircraft and aircraft engines. Skillful application of this discipline enables aircraft and aircraft engines to be designed and their performance accurately assessed without requiring the fabrication and physical testing of prototypes through trial-and-error methods, thereby greatly reducing aircraft design cost and development time. Specific areas which require attention are: improved ability to predict the formation of turbulence and to develop methods for its control; more accurate and efficient computational fluid dynamics (CFD) algorithms; codes and grids for analyzing and optimizing aircraft and engine designs by computer simulation; enhanced techniques for laminar flow control to improve airfoil efficiency; advanced hypersonic, aero-assist and wave-rider vehicle designs; and improved methods to reduce aerodynamic noise and sonic booms generated by aircraft and rotorcraft.

Avionics and Systems Integration

Avionics provide the information and communications processing that facilitates aircraft control, operation, and survival. Systems integration provides the network that links the various electronic and automated devices within an aircraft and its weapon systems. Smaller, lighter, more reliable, and more highly integrated avionics and instruments are required as aircraft become increasingly complex. Specific areas which need priority attention are: highly integrated engine/

airframe controls; advanced electrical and optical subsystems (especially fly-by-light/power-by-wire); advanced sensors to allow aircraft to safely fly in wind shear, heavy rain, icing, and other adverse conditions; and advanced "glass cockpit" technology (replacing conventional gauges and instruments with computer-generated displays).

Human Factors Engineering

Human factors engineering relates to man-machine interfaces and the biomedical aspects of aircrew performance. Advanced, human-centered automation concepts (in which the benefits and capabilities of automation technology are achieved through designs which properly exploit human capabilities) are needed for ever larger, faster, longer flying, and more complex aircraft. Aircraft operation necessarily includes consideration of the safety and productivity of the flight crew, their interaction with the aircraft and air traffic control systems, and the information transfer required for involved operational procedures. As automation and complex computer-based systems are incorporated in flight decks and air traffic control facilities, and as flying times and distances increase, while airports and airspace become more congested, opportunities will arise to improve both productivity and safety. A specific area of human factors engineering which needs increased emphasis is a better understanding of aircrew biomedical limitations (especially fatigue and jet lag), and the countermeasures to change, adapt to, and work around these limitations. In the military area, improvements in aircraft speed, maneuverability, and information acquisition require continuous human factors improvements to ensure that pilots can remain in control of the full range of the system's performance.

Aircraft Manufacturing

Modern aircraft require new and increasingly computerized methods and procedures to design, fabricate, join, and install the advanced aviation materials, structures, engines, and components from which they are made. Also, because of escalating start-up and tooling costs for new aircraft, more efficient and economical processes and management technologies are necessary to remain competitive. Specific areas which need priority attention are: advanced fabrication, lay-up and joining methods for aircraft materials and structures, multi-disciplinary aircraft design techniques, advanced numerical optimization, and advanced computer aided design and manufacture.

Aeronautical Testing

Aeronautical test facilities, such as wind tunnels, engine test cells, and supercomputers, are required to conceive and validate aspects of aircraft design, construction, and operation. A state-of-the-art aeronautical testing infrastructure is therefore required for the United States to design, build, and operate advanced aircraft. Specific areas which require attention are: advanced supersonic and hypersonic wind tunnels; large test cells which can accommodate extremely large engines; advanced aircraft sensors and telemetry devices; supercomputers to perform the calculations involved in numerical aerodynamic simulations; and, perhaps most important, improved academic curricula/techniques and work incentives to attract, develop, and maintain a cadre of skilled aeronautical engineers.

REASONS FOR SELECTION

There are two main reasons why aeronautics is important to the United States. First of all, it is essential for continued dominance of the large world aviation marketplace, which had over $100 billion in aircraft and aircraft-related sales in 1990. The U.S. aviation industry accounts for about 70% of that total, and currently employs over 1 million people. Second, aeronautical technology is the single most important component of military air superiority and troop mobility, whose criticality to national defense was clearly demonstrated in the recent Gulf War.

Commercial and military aircraft are, and for the foreseeable future will remain, high technology products. New classes of aircraft and significant improvements in aircraft performance are therefore attainable only through advances in aeronautical technology. In the commercial arena, prospective advances in aeronautics could make possible the following aircraft: economical and environmentally acceptable supersonic transports (e.g., High Speed Civil Transport successor to the Concorde), vertical take-off and landing aircraft for commuter purposes (e.g., V-22 Osprey tilt-rotor derivative), and significantly more economical subsonic transports (including successors to the Boeing 747). In the military arena, advances in aerospace technology could lead to the following: sustained Mach 3 capability in fighters the same size as the F-15; short take-off and vertical landing capability in fighters with the same size, range, and payload as the F-15; and a doubling of the payload capability of rotorcraft the same size as the CH-47 helicopter.

Aeronautics is both dependent on, and a stimulus for, many other critical technologies cited in this report. For example, the design and testing of more efficient and higher performance aircraft rely to an increasing extent on computing capabilities. The construction requirements of advanced aircraft have stimulated the development of new manufacturing equipment, processes, and management techniques. The operation of and performance requirements for these aircraft have driven the development of high-performance materials and electronics, which have many non-aviation applications.

The relative importance of aeronautics from a research investment standpoint is reflected in the fact that roughly half of Federal funding to industry for R&D goes to the aerospace sector, and that 20 to 25 percent of all independent R&D by U.S. industry is in this sector. Approximately one-third of the total U.S. defense budget is devoted to the research, development, procurement, operation, and support of aircraft. It is important to note that since industry investments in technology development derive from commercial and military sales, market share ultimately impacts technological superiority. Therefore, the United States must maintain a strong commitment to both aeronautical technology development and aerospace market share.

STATUS AND INTERNATIONAL TRENDS

Although post-World War II U.S. manufacturing dominance has been undermined in many sectors during the past two decades, the U.S. aerospace sector has thus far retained its preeminent market position and generated a substantial surplus for the U.S. trade account. U.S. aerospace exports currently outpace imports by a ratio of three to one, for a net annual gain to the U.S. trade balance of almost $20 billion. U.S. companies manufacture roughly three-quarters of all large commercial transports delivered in the 1980s (not including Soviet production). This market share is declining due to an aggressive Airbus Industrie effort and is likely to worsen if the United States fails to maintain a strong commitment to aeronautical technologies.

U.S. military exports outpace imports by a ratio of four or five to one. However, the United States is now less dominant in worldwide military aircraft sales because many countries have fostered indigenous military aircraft production. Moreover, U.S. export of military aircraft is coupled to U.S. defense and foreign policy and is therefore controlled. The large commercial transport market will become increasingly important to aerospace sales and technologies as U.S. and foreign defense budgets decline in the 1990s. This trend is likely to encourage foreign governments to support efforts by their domestic aerospace producers to shift resources from military to commercial aircraft design and production.

Foreign governments have provided support for their indigenous aerospace industries through direct subsidies and other policies that favor domestic production. These policies, along with other market factors, such as high product-line start-up costs, have facilitated a trend toward international consortia to develop, produce, and market aircraft and aircraft engines, components, and parts. In order to promote foreign sales, U.S. aircraft and aircraft engine producers have purchased increasing quantities of foreign-made parts and components for use in their finished products. These practices have been a double-edged sword for U.S. aerospace companies. They have facilitated the diffusion of aeronautical technologies from the United States to other countries and have stimulated a sharp rise in aircraft and engine parts imports. However, they have also ensured continued U.S. access to foreign aerospace markets.

Partly as a result of direct government support, Western Europe is now on a par with the United States in aerodynamics and structures and is slightly ahead in some advanced materials applications to new aircraft designs. European propulsion and avionics capabilities are somewhat behind the United States. Japan has instituted a large, well-coordinated government and industry R&D program, which may improve the Japanese technology base and close what has been a significant gap between it and the United States. The United States continues to lead in systems integration technologies, although Western Europe and Japan have made progress in this area. As a measure of the importance of aeronautics in the world, other countries such as Brazil, Israel, and Australia have developed advanced aircraft.

Market share in commercial transport aircraft depends on many factors in addition to advanced technology. However, to compete at all in this era of direct foreign government subsidies, the technology in U.S. aircraft must be better than that of its competitors. For the United States to even maintain its current market share, it must continue to make significant advances in aeronautical technology.

SURFACE TRANSPORTATION TECHNOLOGIES

DESCRIPTION OF TECHNOLOGY

Surface transportation technologies offer important potential contributions to more efficient and cost-effective transportation systems for the nation. Two sets of technologies that are particularly important to the future of surface transportation are intelligent vehicle/highway systems and compact vehicular energy sources (especially more efficient batteries for electric powered vehicles). The advantages of each technology to transportation systems will become evident only if trade-offs with existing or alternative systems can be weighed. Each concept must be designed, developed, tested, and evaluated in an intermodal competitive context.

Intelligent Vehicle/Highway Systems

Intelligent vehicle/highway systems (IVHS), often referred to as "smart cars" and "smart highways," use advanced technology to increase safety, system capacity, operational efficiency, and driver convenience; reduce emissions, fuel consumption, and congestion; and provide mobility to drivers with diminished skills (e.g., the elderly and the handicapped) by improving the interactions among the driver, the vehicle, and the roadway. The emphasis is on the total "driver-vehicle-roadway system." The addition of an information and control infrastructure to the existing physical transportation infrastructure will result in a fundamentally different system, which will have an enormous impact on drivers.

Recent advances in electronics, sensors, computers, and communications provide a major opportunity for breakthrough improvements in crash avoidance and highway traffic management. A vast array of new driver information, communication, and vehicle control systems is currently under development by the automotive and electronics industries around the world. Advanced technology allows the development of systems that will monitor, control, and manage highway traffic much like an air traffic controller at an airport; provide pre-trip and in-route, real-time information with regard to optimum routes from origin to destination and navigational assistance; help drivers better sense impending dangers; sense lapses in their judgment and skills; aid them in performing their driving task; and compensate for some errors.

Intelligent vehicles and highways will accomplish these objectives by applying and integrating many other National Critical Technologies. For example, advanced traffic management systems incorporate technologies such as sensors (detector and surveillance technologies), microelectronics, software, and high-performance computing to manage traffic flows more effectively. These systems will increase capacity on existing or slightly modified/upgraded infrastructure, reducing pollution, energy losses, and other adverse effects associated with overburdened roadways.

A related set of technologies deals with advanced vehicle controls. These technologies will enable improved handling, greater vehicle stability, and size reductions. These improvements, in turn, will permit reduced lane width and increased density of traffic on highways and city streets without sacrificing safety or convenience.

Compact Vehicular Energy Sources

Electrically powered vehicles are an extremely important focus of surface transportation research and development. However, these vehicles can become convenient and cost-effective alternatives to conventional vehicles only with the development of advanced battery and fuel cell technologies (see ***Energy Technologies***) and the resolution of potential environmental concerns. Battery technologies of potential value include conventional lead-acid types, as well as systems based on lithium, aluminum-iron sulfide, sodium-metal chloride, sodium-sulfur, zinc-bromine, and iron-air combinations.

A number of design, engineering, performance, and lifecycle problems must be solved before electric vehicles come into widespread use, even though the basic technologies are understood in principle. Prototype electric vehicles have attained top speeds of 50 miles per hour and have a range in excess of 100 miles before recharging. In addition to these speed and range constraints, conventional lead–acid batteries must be replaced at least every four years at substantial cost. Improved aerodynamic vehicle design, utilization of lighter weight materials, and use of low resistance radial tires can all contribute to vehicle efficiency. (These improvements can be incorporated into new internal combustion vehicles to achieve higher fuel efficiencies as well.)

Moreover, battery–powered vehicles may not be environmentally benign in a systems context. Although they do not produce exhaust emissions while in operation, the generation of electrical power required to charge the vehicles could have undesirable environmental impacts at the source. The development of immobile and relatively remote generating stations, however, can facilitate the identification and minimization of pollution problems. Another potential environmental problem could be caused by the disposal of spent batteries. Thus, options for recycling and reusing must be developed (see ***Pollution Minimization, Remediation, and Waste Management***).

Fuel cells are another alternative power source that offers great potential to provide the high energy densities needed to meet future transportation requirements. Fuel cells, based on non–petroleum fuels, could provide improved efficiency and reduced emissions compared to current internal combustion engines. Proton exchange membrane (PEM) is a particularly promising fuel cell technology that has certain advantages over phosphoric acid fuel cells in transportation applications. These advantages include reduced size and weight, faster start–up, better transient response, increased reliability, and potentially lower cost. (See ***Energy Technologies*** for further discussion of fuel cell technology.)

Other Technologies

Other technologies of current interest emphasize incremental improvements in performance of conventional systems. Widespread use of microprocessors in automobiles, for example, can control emissions and optimize engine efficiency. Further advances in this area could lead to the replacement of mechanical parts with smaller, more efficient electronic components, improving engine performance, fuel economy, and maintenance records.

As demands on transportation systems grow, so will the difficulties associated with maintaining existing infrastructures. This is especially true in the highway infrastructure, where needed maintenance is often deferred because of unacceptable disruptions in service. This practice compounds the problems of deteriorating roadways and declining system efficiency. This challenge must be addressed on several fronts. Advances in materials technologies, for example, could lead to paving and repair materials with higher strength, more durability, and greater ease in surfacing. Strategic management systems focusing on all aspects of the highway system, including structures, pavements, safety, traffic control, operations, and maintenance, are essential for optimizing already overburdened transportation resources.

Magnetic levitation (maglev) systems may have potential applications in urban, suburban, and intercity travel markets, particularly between cities that are 100 to 500 miles apart. This technology uses magnetic lift to raise the vehicle off a guideway, thus eliminating rolling friction. Several maglev systems have been designed and used outside the U.S.

REASONS FOR SELECTION

The U.S. transportation infrastructure is vital to the nation's economic growth and international competitiveness. There are various signs, however, that the system is beginning to break down. Transportation networks in major urban areas in the United States are overburdened. Many existing roads and bridges can no longer accommodate traffic increases through expansion or modification of existing roadways. Furthermore, there are few places to build new roads, especially in densely populated urban areas, placing severe constraints on the ability to reverse deterioration of the infrastructure and to handle future growth.

Existing transportation infrastructures have created widespread problems such as air and noise pollution. Supplies of conventional (primarily liquid) fuels that feed the transportation systems in this country are unstable and finite. These problems create the need to find alternatives to existing systems, to identify new and more practical means for mass transportation, to manage current systems more efficiently, and to minimize the negative consequences of conventional systems.

None of the approaches outlined here will eliminate problems facing the nation's transportation networks. Nor are the vehicle technologies described here envisioned as replacements for well-established modes of transportation such as automobiles powered by internal combustion engines. Instead, the technologies are incremental improvements in systems, operations, and management that will produce long-term benefits in maximizing the utilization of scarce resources -- including land, space, fuels, and time.

STATUS AND INTERNATIONAL TRENDS

Many of the surface transportation technologies and applications rely on other National Critical Technologies, including materials, communications, electronics, and simulation and modeling. Thus, the successful development, application, and commercialization of surface transportation technologies is dependent upon advances in these other fields as well.

Both Europe and Japan have initiated ambitious intelligent highway programs, although two European programs stand out. These are the Program for European Traffic with Highest Efficiency and Unprecedented Safety (PROMETHEUS) and the Dedicated Road Infrastructure for Vehicle Safety in Europe (DRIVE). U.S. initiatives on intelligent vehicle/highway systems center on research, development, and field testing of proven technology. These activities involve Federal, State, and local government offices, as well as the private sector. Field trials for advanced traffic management and traveler information systems will be carried out for at least four systems in several states. Another major initiative being undertaken in the United States is the Program for Advanced Technology for the Highway (PATH).

Many of the obstacles to the implementation of these concepts involve policy, regulatory, and institutional issues as well as numerous human factors. It is important to work toward the resolution of these issues, in addition to achieving progress in the maturation and development of specific technologies.

For electric powered vehicles, battery life and power ratings remain the single most important challenge. While improvements have been made, both extending the range of battery-powered vehicles and prolonging their life cycles are essential if they are to compete with conventional gasoline-powered vehicles in the near-term, even as a supplemental means of transportation. None of the advanced batteries now being tested in high density, compact form -- nickel-iron, nickel-cadmium, zinc-bromine, lithium-iron sulfide, sodium-sulfur, metal-air -- are commercially available and all of them require considerable engineering development before they can be brought to the marketplace.

Maglev technology has been the subject of substantial R&D and demonstration efforts for more than 20 years, primarily in Germany and Japan. Its use in city operation at low speeds is well proven in those countries, but high speed systems are still being tested and evaluated. The practicality of using maglev in the United States, given the need to consider density of population centers, construction costs, rights of way, and competing alternatives, is still to be determined.

ENERGY AND ENVIRONMENT

- Energy Technologies
- Pollution Minimization, Remediation, and Waste Management

ENERGY AND ENVIRONMENT

A wide range of promising technology applications responds to the pressing national need to reduce use of fossil fuels, reduce the import of liquid fuels, and minimize adverse environmental impacts of modern industrial society. Energy source issues include energy efficiency, cost–effectiveness, and the minimization of adverse environmental impact. However, there are trade–offs in these three areas with virtually every alternative energy source and storage technology. No single technology offers the promise of limitless energy at minimal cost and environmental impact.

Promising energy source technologies include renewable energy technologies (including solar thermal power generation, photovoltaics, alternative fuels, and biomass processes), nuclear fission, and environmentally improved processes (such as fluidized bed combustion). Other promising energy technology areas include improved conservation and storage technologies. Some of the more promising energy technologies ultimately could replace more conventional fossil fuel power sources, but at present all except nuclear fission are viewed as incremental technologies to meet rising energy demand and to manage energy loads more efficiently. None of the source technologies, even in combination with efficient storage, are viewed as short–term replacements for conventional energy sources for a combination of technological, economic, and regulatory reasons. Realizing the potential of these new energy technologies depends on further advances in information technologies (notably electronics, sensors, and simulation and modeling), materials, and other National Critical Technologies.

In environmental technologies, trade–offs again exist among pollution minimization, cost, remediation, and waste management. Although significant environmental improvements could be made through more widespread application of proven control technologies, the solution to serious emissions and toxic waste problems will need significant advances in minimization, remediation, and waste management technologies. Like the energy area, environmental technologies are closely linked with continuing advances in a range of other critical technologies.

The technological issues associated with energy and the environment are substantially intertwined. An integrated approach to energy and environmental issues will produce more effective utilization of new and emerging technologies.

ENERGY TECHNOLOGIES

DESCRIPTION OF TECHNOLOGY

There is a critical need to reduce the nation's reliance on oil, and especially on supply sources under the control of unstable or unfriendly governments. There also is growing concern about the environmental impact of global increases in energy use and the effects of higher concentrations of "greenhouse" gases in the atmosphere. However, a shift to alternative energy sources inevitably will involve trade–offs in the areas of cost, system efficiency, and environmental impact. Since no energy source offers limitless supplies, low costs, and zero environmental impacts, a total systems approach must be employed to identify new opportunities and assess their potential drawbacks. The technologies involved in improved energy sources, energy conservation, and energy storage can bring us closer to these energy goals.

Energy Sources

The United States and other nations are exploring a variety of alternative energy options. Although many of these show promise of providing reliable energy supplies in the future, further improvements in cost–effectiveness and technological and market developments are required. Technologies with the potential to achieve these aims fall into two broad categories: renewable energy sources and environmentally improved technologies, which are directed toward utilizing traditional fuels while minimizing the drawbacks normally associated with them. In addition to central power station applications, these technologies can often be applied in modular form to satisfy peak demand surges, restrain the growth of fossil fuel consumption, and alleviate the need for construction of new conventional power plants to meet peak loads.

Renewable Energy Technologies. Solar thermal power generation, photovoltaics, wind turbines, and biomass/alternative fuels are among the most promising of the alternative renewable energy technologies. Solar heating of buildings and water is utilized worldwide, with varying commercial success. In addition, thermal power can generate electricity by utilizing reflective surfaces to concentrate sunlight onto a receiver. Trough electric systems use a parabolic reflector with a receiver that runs along its focal line. Dish/Stirling systems use a parabolic dish that focuses sunlight to a single point near the engine and generator. Central receivers use individually controlled heliostats or mirrors located on the ground to reflect and concentrate sunlight onto a receiver located on a tower. The higher the concentration, the higher the temperatures generated in the system, and the more efficient is the generation of electrical power.

Photovoltaic devices directly convert solar photon energy into electrical current by separating light–generated charge carriers by a built–in electric field at the interface of the semiconductor layers. Silicon, copper indium diselenide, cadmium telluride, and gallium arsenide are the principal materials used in their production. An important determinant of the commercial potential of photovoltaics is cell and module efficiency. Current flat plate photovoltaic modules have efficiency rates of 5 to 10 percent, with estimated lifetimes ranging from a few years for older technologies, to as much as 20 years for newer ones. Costs must be reduced for photovoltaics to compete with other utility–scale sources.

Wind turbines convert wind into useful mechanical or electrical energy. The conversion process utilizes basic aerodynamic forces to produce net positive torque on a rotating shaft. This results in mechanical power, which can then be converted to electrical power. Higher efficiencies can be achieved through improved design tools, advanced airfoils, improved manufacturing, and better site selection.

Research is also underway on alternative fuels for transportation and other uses, with a focus on biomass processes. These include various alcohols in pure form or blended with petroleum–based products. Grains, sugar, wood, plant wastes, and other organic materials with high cellulose content are the feedstocks for producing these fuels. Methane production for heating and other purposes is another potential source to reduce demand for traditional energy sources.

Environmentally Improved Technologies. The United States has large reserves of coal that theoretically could satisfy energy needs for centuries. Exploitation of this resource is limited by economic and environmental concerns. More complete understanding of combustion and catalytic processes could result in cleaner, more efficient power generation technologies. A fluidized bed combustor continuously feeds small particles, typically coal particles, into a chamber through which large volumes of combustion gases flow. Potential advantages of this process are lower emissions and more complete combustion.

Nuclear fission is the only currently available technology capable of producing large blocks of electrical energy without direct emissions of carbon dioxide, sulfur oxides, and nitrogen oxides. However, vigorous research and development of advanced designs for light water, gas-cooled, and liquid metal reactors is needed to ensure that our plants are the safest, most reliable, and most efficient possible. These designs promise to enhance safety margins substantially through passive response to non-normal conditions, use of simplified systems, and inherently improved thermal management and tolerance. These enhancements should translate directly into better public acceptance. Second generation nuclear technologies resulting from research and development could provide, according to conservative projections, 140 GW of new capacity by 2030. Nuclear power would then reduce carbon dioxide emissions by 24 percent from alternative scenarios.

In contrast to fission, nuclear fusion technology is not considered by the Panel to be a current critical technology because of the long development lead-times anticipated for commercialization.

Energy Conservation

The focus of energy conservation is on those technologies that will directly reduce energy demand. More efficient manufacturing processes, reduced energy loads in buildings, and efficiency gains in transportation are among the areas that are critical to our energy future.

Energy efficiency gains and conservation measures benefit the economy, which grew by 46 percent since 1973, while growth in energy demand was limited to only 11 percent over the same period. Significant additional improvements are essential to moderate energy consumption while promoting economic growth. In addition, while total energy demand has grown moderately in the United States, rising demand in certain energy sectors, electricity, for example, has continued unabated. This necessitates efficiency improvements in power generation and distribution, as well as more efficient end use.

Considerable research into energy efficiency technologies continues and will produce future payoffs for the nation. Many of the technologies and sciences that will improve future efficiency have been identified in the National Energy Strategy and other analyses. The technology thrusts include:

- Combustion research to better understand the mechanism and kinetics of fuel consumption
- Research into the mechanisms of heat transfer in solids and fluids
- Analysis of material chemistry and development of materials processing methods
- Advanced materials research in high- and low-temperature applications
- Surface science, coatings, and lubricants to gain efficiency improvements in precision machining and in rotating machinery.

Representative of existing and emerging technologies are building energy conservation technologies, which include factory-produced housing (i.e., the use of modular components that reduce energy consumption by unifying wiring, water pipes, and other items rather than installing them separately); advanced materials for housing and commercial buildings; energy-efficient lighting, appliances, and equipment; and sensor technology that can shift heating and cooling to those parts of a building that need it the most over the course of a day. "Superwindows" (double-paned windows made of transparent but nonconducting material) offer vastly improved insulation capabilities, with resistance values (R–values) of above R–19, compared with the R–3 that is available from normal double–paned windows.

The design and development of more inherently efficient manufacturing and production processes would improve the competitiveness of U.S. industry while reducing energy demand. In many instances, reduced energy consumption through more efficient process design would also minimize environmental problems associated with industrial processes. (See ***Pollution Minimization, Remediation, and Waste Management***.)

Energy Storage

Energy sources and storage are linked inextricably. One critical problem in the delivery of energy is the mismatch between the rates of production and use. Solving this problem involves a combination of storage and transmission of power from those areas with excess capacity at a given time of the day to those areas with a capacity shortfall. Promising technologies will allow more effective utilization of present energy sources, as well as provide a new means to satisfy the mobile power requirements of electric vehicles and peak electric power demands of the future. Improved battery and fuel cell technologies are required to achieve these objectives.

Batteries. Batteries are more efficient than mechanical storage systems, but their primary advantage is their flexibility, which allows them to be sited near intended load areas. Other advantages include their near–zero emission levels, minimum noise levels, and their ability to charge and discharge rapidly. Operation and maintenance requirements also are low, although battery production and disposal of expended batteries pose environmental concerns. Improvements in cost, weight, and operating lifetimes are required to achieve widespread utilization.

Promising battery technologies include well–known lead–acid types, as well as lithium, aluminum–iron, sodium–metal chloride, sodium–sulfur, zinc–bromine, and iron–air batteries. Advanced lead–acid and zinc–chloride batteries could have applications for utility scale energy storage in the future. The former offers incremental efficiency gains over conventional lead–acid batteries and the latter is viewed as the most advanced in terms of research. A major advantage of zinc–chloride batteries is that their discharge rates can be controlled. This would have important implications for both utility grid and transportation applications.

Fuel Cells. Fuel cells are used to generate electrical power through controlled reactions of hydrogen and oxygen in the presence of an electrolyte. A fuel cell powerplant consists of three basic elements: a fuel processor that extracts hydrogen from any hydrocarbon fuel, a power section that consists of several stacked cells, and a power conditioner to transform direct current into alternating current. Since the process that generates electrical power is electrochemical, not mechanical, a fuel cell contains no moving parts and does not involve combustion. It is possible that fuel cells can be constructed on varying scales, from individual units, to power–moving vehicles, to larger scale plants for commercial electricity generation.

Fuel cell technology offers several potential advantages over existing power generation and storage methods. Fuel cells can be used for a variety of power needs, from small–scale applications to larger ones. They are less dependent on location to satisfy their role in energy demand, so they could be suitable for remote power generation and storage. The environmental impact is presumed to be less than that of conventional technologies, and potential feedstocks are abundant. Its simplicity could mean high availability rates, as much as 80 to 90 percent in the case of larger–scale power plants.

REASONS FOR SELECTION

Petroleum and other fossil fuels are finite natural resources that are basic to modern life — generating power for homes, industries, and transportation for most of the world's population. The long–term prospects for achieving energy security and maintaining economic growth are uncertain unless alternative energy solutions are identified. While efficiency gains have enabled this country's economy to expand at a significant rate over the past decade with limited increases in total energy consumption, the worldwide demand for fossil fuels, especially petroleum, will increase if alternatives are not developed. Although fossil fuels will remain the primary energy source for the United States in the foreseeable future, economical and "cleaner" alternatives must be identified and developed to meet anticipated increases in demand, while laying the groundwork for implementing a replacement strategy over the long term.

Central to this effort is the development of more effective means of accessing and storing energy. One of the most important factors in the escalating cost of delivering electric power to users today is the fact that energy must be delivered as it is demanded. Thus, generating systems and infrastructures must be geared toward peak demand periods, even though those periods occupy only a portion of a day's total power needs. Effectively combined energy production and storage technologies could reduce demands on electric power generation infrastructures, provide the flexibility needed to achieve steady utilization rates, and address pollution control and conversion efficiencies.

STATUS AND INTERNATIONAL TRENDS

Despite their commercial promise and the worldwide research momentum, the future commercialization of energy source, conversion, and conservation technologies is dependent on the ability to overcome a number of technical obstacles and constraints, which include the following:

- Limited knowledge of fuel chemistry leads to less than ideal extraction of chemical energy from fossil fuels as well as generation of undesirable pollutants

- Development of solar energy technologies requires an improved understanding of fundamental properties and mechanisms of photon-matter interaction, including photosynthesis

- Materials research is required to reduce manufacturing costs. (Resistance to degradation and more suitable materials would help achieve higher efficiencies in capture, conversion, transmission, and storage of energy.)

Energy Sources

Government and private sector research has resulted in significant breakthroughs for solar power generation, and DOE estimates that solar energy systems could be a multibillion dollar market for U.S. firms. Solar technologies are becoming increasingly cost-effective. Power plants operated by Southern California Edison initially generated power at a cost of $0.24 per kilowatt-hour; second generation systems will generate power at an estimated $0.08 per kilowatt-hour, with further cost reductions of 30 percent or more attainable.

Research is now being performed by other nations, and potential international competition is particularly strong in photovoltaics. Germany's research budget on photovoltaics is 65 percent larger than that of the United States. Japan's photovoltaic research is 40 percent higher. Even though it is still a fledgling industry, the U.S. market share of the photovoltaic industry has fallen from 65 percent in 1981 to 31 percent in 1988. The technological key to tapping the solar resource is in improving conversion efficiencies and reducing system costs. Among the associated technologies that would enable further advances in solar power are: optical materials and advanced optical techniques to improve light gathering efficiencies and reduce costs; better semiconductors to improve conversion efficiency; high-temperature materials to enable receivers to absorb sunlight more efficiently; low-cost and lightweight heliostats and parabolic dish collectors; and advanced molten-salt and direct absorption receivers for central receiver systems.

Energy Storage

Capital costs and inherent efficiency limitations constrain the use of currently available batteries for mobile and stationary power storage. Few, if any, new battery types are near commercialization. Current research is directed largely at achieving breakthroughs that would enable the use of advanced batteries in transportation (see ***Surface Transportation Technologies***). Several other proposed battery technologies, including iron-chromium, zinc-ferrocyanide, nickel-hydrogen, and lithium-iron sulfide, are considerably less mature.

Fuel cell technology has been demonstrated in the United States and Japan, with 38 small-scale demonstration plants in operation by the mid-1980s. Limitations in fuel cells include the effectiveness of electrolytes (the medium in which the electrochemical reactions actually take place), the high cost of constructing and maintaining power sections, and efficiency losses due to poor system integration. One important limiting factor is that, due to their relative inefficiency, fuel cells require far larger installations to generate power on a commercial scale than many conventional processes. Periodic replacement of fuel cell stacks also could prove detrimental, since current fuel stacks need to be replaced at least every 40,000 hours of operation if working at full capacity.

POLLUTION MINIMIZATION, REMEDIATION, AND WASTE MANAGEMENT

DESCRIPTION OF TECHNOLOGY

Environmental pollution -- contamination of air, soil, and water -- occurs in many forms and is highly pervasive. U.S. industry alone generates more than 300 million tons of liquid and solid hazardous wastes and another 600 million tons of nonhazardous wastes annually. Some pollution minimization and remediation strategies involve more widespread application of existing technologies and more efficient management methods, rather than new technologies to reduce the consequences of pollution. According to one estimate, environmental contaminants could be reduced globally by as much as 50 percent if currently available technologies were utilized in all stages of industrial production.

However, more widespread application of current technologies will not be enough to solve serious existing and future environmental problems; new technologies will be required. Many of today's processes and technologies simply transform pollutants into a more manageable form, rather than neutralize or convert them into benign substances that can be discarded. The elimination of one pollution problem often results in the creation of others. For example, separation processes might create more easily handled wastes that can be incinerated. Although the treatment prevents potentially toxic substances from entering into water supplies, incineration could result in toxic air emissions or residual wastes that pose disposal problems of their own. Thus, future technology must systematically address the source of the problem, not just the pollutants.

The nation's priorities within this technology area focus on economical minimization technologies and techniques; recycling/re-use of final products and production by-products; and the treatment of waste products or the disposal and storage of those wastes that cannot otherwise be accommodated. Remediation is the final stage in this waste management strategy, focusing on restoration of damaged environments or reduction of toxicity to acceptable levels. It is unrealistic to expect total elimination of all pollutants, but skillful waste management utilizing appropriate technologies in all four phases outlined above can reduce wastes to more manageable levels and reduce risks to society.

Minimization

Pollution minimization involves the reduction of polluting outputs at their source, generally the manufacturing process, and the implementation of improved production techniques to reduce potential pollutants from the outset. Source reduction can be achieved through product changes, the use of less toxic materials in production, equipment redesign, and/or process modification. Private sector firms recognize that instituting pollution minimization strategies can also lead to improved production efficiency and commercial opportunity.

Specific strategies and tools vary from one industry to the next, but the common thread of these strategies is that pollution is controlled and minimized by incorporating new elements into processes, particularly elements that will simultaneously improve production processes, rather than relying on "end of pipe" add-on controls. This is partially achieved through the optimum utilization and efficient control of inputs. An example of a minimization strategy is the use of agricultural technologies that can sustain production with less reliance on fertilizers and pesticides.

Recycling/Re-use

Having reduced the generation of pollutants through minimization actions, recycling and re-use can further diminish the volume of potential pollutants resulting from production. Recycling can also benefit industrial processes, where chemical and other wastes are identified for re-use. Closed loop processes in particular can reduce waste products and improve production efficiency.

Materials in industrial processes are amenable to recovery and recycling if their physical and/or chemical attributes allow them to be easily separated from process effluent. A typical recovery/recycling system will use several technologies in sequence. Standard technologies that can be adapted for the recovery of raw materials or by-products may be grouped in three general categories:

- **Physical separation**, which includes gravity settling, filtration, flotation, flocculation, and centrifugation
- **Component separation,** which relies on differences in electrical charge, boiling points, or miscibility
- **Chemical transformation**, which relies on chemical reactions to remove specific components.

The maturity of different recovery and recycling technologies varies and there are trade-offs involved in their use. Physical separation techniques, for example, are relatively well developed and inexpensive, but they are not as efficient as other techniques. More complex processes, such as reverse osmosis, are far more costly and have only been implemented for hazardous waste reduction on a limited scale.

Treatment, Storage, and Disposal

Treatment technologies address processing of pollutants that cannot be re-used and must be discarded or stored in a way that minimizes any dangers to the environment. An overriding consideration in treatment is to reduce the total volume of potential pollutants so that they can be more easily managed. Separation techniques commonly used for recycling/re-use are among the simplest and least costly means of reducing the volume of pollutants, especially liquid wastes. One promising technology in this area is supercritical water oxidation (SCWO). In SCWO, organics are oxidized in the presence of a high concentration of water that is brought to temperatures and pressures above its critical point. This technology has been demonstrated successfully in the treatment of many industrial and nuclear wastes. It may also be applicable to mixed wastes and, since it can process highly dilute process streams, it obviates the need for preprocessing.

Not all wastes can be recycled or converted into totally benign substances. Although various treatment technologies can reduce the volume of pollutants, many wastes still require safe storage and/or disposal. Toxic wastes that are concentrated by treatment technologies can be stored more easily and in a manner that poses a more identifiable and manageable risk than untreated waste.

The storage and disposal of nuclear wastes is a difficult problem. Nuclear disposal traditionally has involved the burial of wastes underground and/or storage of wastes in containment pools. Because of the long time period required for many forms of radioactive wastes to decay and the high toxicity of these wastes, secure disposal and storage methods are required. Research to find alternative means for disposing of high- and low-level nuclear wastes continues to be warranted.

Remediation

In contrast to the avoidance of pollution through minimization or its reduction through treatment, remediation technologies restore contaminated environments to their original condition or reduce levels of toxicity to a point where they pose no significant dangers. A number of remedies already exist and others offer potential for dealing with toxic pollutants that were considered to be virtually untreatable a decade ago. Among these advances are soil washing techniques, in which contaminated soils are treated with chemical agents that permit the separation of both organic and inorganic contaminants; thermal desorption, in which contaminated materials are heated to release toxic pollutants in a gaseous form; and composting processes that transform organic contaminants through biodegradation.

A remaining technical issue in remediation is that the number of treatments required can be extremely high -- at least equal to the numbers and types of pollutants entering soil, water, or air. At present, few technologies can effectively restore areas damaged by more than one form of pollutant.

One very promising new technology is bioremediation, which uses recombinant or naturally occurring bacteria to ingest pollutants that would require years to eliminate through natural processes or that pose permanent dangers to the environment (such as inorganic toxic wastes). According to one estimate, bioremediation of toxic wastes could be only 10 percent as expensive as conventional treatment and storage processes, without creating attendant problems with leftover wastes that require supplementary treatment. In a set of recent applications that received wide attention, bioremediation was used to treat devastating oil spills in Alaska and Texas. In other applications, microbes break hazardous compounds into less dangerous substances, which can then be incinerated or treated with conventional technology.

Risk Assessment

Systematic utilization of waste management and pollution control technologies relies on the effective use of risk assessment methodologies, which can estimate the form, dimension, and characteristics of environmental risks and determine threats associated with new products or their by-products. Risk assessment tools are used to address diverse analytical problems in areas that extend from biotechnology and agriculture to energy and the environment.

Improved risk assessment techniques can make a major contribution toward systematizing and prioritizing waste management actions. Development priorities include improved testing methods, environmental modeling, and sampling techniques. Simpler, more reliable, and faster monitoring and testing equipment is also important. New devices in such areas as supercritical fluid extraction for sample preparation, and environmental immunoassays for on-site screening of test samples, offer the promise of more reliable and less expensive monitoring and testing. This will, in turn, lead to a more accurate understanding of the hazards posed by specific forms of pollution and waste.

REASONS FOR SELECTION

The dollar cost of combating pollutants is huge, even before the impact on health and welfare is considered. Industry spends $46 billion annually on pollution controls to meet existing regulations. Disposal costs are increasing as well, amounting to over $240 per ton at many sites. Eighty percent of existing landfill space will close permanently over the next fifteen years, further exacerbating the problems and costs associated with disposal of solid waste. Potential economic and health benefits from improved minimization and remediation techniques are significant. Pollution minimization issues are closely linked to other national needs and concerns, including energy use and industrial efficiency.

Nuclear waste disposal is a particularly difficult problem because of the paucity of feasible storage sites, the long time required for materials to decay to less hazardous levels, and the potential danger posed to humans, animals, and the environment. Today, 110 nuclear power plants generate about 20 percent of all electricity used in the United States. Due to problems with safe disposal and other obstacles, more than 100 additional plants have been cancelled or permanently deferred. Even with the cutbacks in nuclear plant construction, disposal is a long-term problem. For example, spent fuel from existing plants is expected to reach 44,000 tons by the year 2000, and disposal options remain severely limited. Storage and disposal of low-level nuclear waste also pose significant long-term consequences, since low-level wastes must decay for many decades before reaching levels of toxicity that are believed to be nonthreatening to health or safety.

STATUS AND INTERNATIONAL TRENDS

Environmental problems are now receiving global attention. Unfortunately, no single technology promises to be a "silver bullet" that will cure all the nation's waste treatment and disposal ills. The development of a broad range of technologies will be required. This is particularly true of mixed wastes (e.g., chemical/radioactive wastes), where the processes used to treat an individual component might be useless or even counterproductive if used on the mixed waste. This creates the need for hybrid solutions that are tailored to each particular problem. Another complicating factor in the assessment of worldwide trends is that different nations have adopted different philosophies and strategies for waste management. For example, incineration is being aggressively pursued by some nations to solve the problem of urban solid waste disposal even though it often leads to substantial air pollution.

Developments in the area of pollution minimization, remediation, and waste management are extensive, and new technologies are being brought on-line incrementally through international research efforts. Many pollution control technologies are mature and have been in widespread use for decades. Because of relatively early enactment of pollution control legislation in the United States, U.S. industry has been a leader in "first generation" technologies that relied on chemical processes (e.g., water treatment plants and scrubbers). However, advanced pollution control technologies could involve different processes, and much work remains to be done to develop and commercialize effective and efficient approaches. For example, significant challenges remain before bioremediation can be practiced on a wide scale. The first is identifying the types of microbes that can be utilized for cleanups, since almost every toxic substance requires a unique treatment. More than 200 potentially hazardous compounds are contained in PCBs alone; many of these compounds have been mixed with other chemicals and pollutants in toxic waste sites and must be separated before treatment can begin. A second challenge is to develop new bacteria by recombinant methods or adapt bacterial forms to improve their effectiveness.

APPENDICES

APPENDIX A

NATIONAL CRITICAL TECHNOLOGIES: LEGISLATION, PANEL, AND METHODOLOGY

APPENDIX A
NATIONAL CRITICAL TECHNOLOGIES: LEGISLATION, PANEL, AND METHODOLOGY

LEGISLATION

The National Critical Technologies Panel was established by the Fiscal Year 1990 Defense Authorization Act (P.L. 101–189) through an amendment to the National Science and Technology Policy, Organization, and Priorities Act of 1976. The legislation further mandated preparation and submission of a biennial report on the nation's critical technologies to the President and the Congress through the year 2000.

The Panel was charged with identifying up to 30 "national critical technologies." These technologies were defined as areas of technological development which are "essential for the long-term national security and economic prosperity of the United States." Process as well as product technologies were to be considered.

PANEL

Each Panel is to consist of 13 individuals with expertise in the fields of science and engineering, chosen from the Federal government and the private sector. The Director of the Office of Science and Technology Policy (OSTP) appoints nine of the panelists, of whom three must be U.S. government officials and six must represent private industry or higher education. The Director appoints as Chairman one of the Federal officials serving on the Panel. In addition to the nine panel members appointed by the Director of OSTP, the agency heads of the Department of Defense, Department of Energy, Department of Commerce, and the National Aeronautics and Space Administration each appoint one representative to the Panel.

Panelists appointed by the Director of OSTP for this initial study were chosen in an effort to ensure that the Panel would include a balanced set of members with expertise covering a broad range of key technological areas as well as possessing a broad interest in issues of national security and economic competitiveness. The Federal agency heads were also encouraged to appoint individuals with appropriate technical backgrounds whose government positions provided a policy-level perspective on technology issues. Current Panel members are listed in Table A–1.

Table A–1. National Critical Technologies Panel: 1990–91

William D. Phillips, Chairman Associate Director for Industrial Technology Office of Science and Technology Policy Executive Office of the President	**Alexander Rich** Sedgewick Professor of Biophysics Massachusetts Institute of Technology
Frederick M. Bernthal Deputy Director National Science Foundation	**Robert Rosen** Deputy Associate Administrator for Aeronautics, Exploration and Technology National Aeronautics and Space Administration
Charles M. Herzfeld Director of Defense Research and Engineering U.S. Department of Defense	**Charles V. Shank** Director Lawrence Berkeley Laboratory
Ruth L. Kirschstein Director National Institute of General Medical Sciences National Institutes of Health	**John C. Tuck** Under Secretary U.S. Department of Energy
Robert W. Lucky Executive Director of Research Communication Sciences Division AT&T Bell Laboratories	**Albert R.C. Westwood** Vice President, Research and Technology Martin Marietta Corporation
Richard C. Messinger Vice President and Chief Technical Officer Cincinnati Milacron	**Robert M. White** Under Secretary for Technology U.S. Department of Commerce
	James E. Worsham Chairman GPA Asia Pacific (former President, Douglas Aircraft)

METHODOLOGY

The Panel began its deliberations by reviewing recent studies on critical technologies, with particular emphasis on the criteria and methodologies for selection of critical technologies. Each of these studies had a unique focus and contributed useful input. Briefings were presented by a number of organizations that have been examining these issues. The Panel, however, assumed responsibility for assembling a comprehensive list of National Critical Technologies. The importance of establishing a careful, step-by-step methodology for selection of the technologies, which subjected candidate technologies to screening against a set of approved evaluation criteria, was recognized.

A taxonomy was developed which placed technologies within a general hierarchy and highlighted interrelationships. The Panel noted that many of the prior studies listed technologies at differing levels of taxonomic aggregation and concluded that it was probably not practical to be consistent in presenting all critical technologies at the same level of aggregation. However, in order to understand and recognize the hierarchical relationships, the taxonomy was developed and refined and employed as a candidate list from which to make selections. The Panel then established criteria and ground rules for selection, shown in Table A–2. These criteria were intended to highlight the importance of individual technologies to national security, the national economy, and to meeting other national needs. The criteria were employed as a general framework within which to assess the "criticality" of candidate technologies. Primary consideration was given to technologies that could be incorporated into commercial products/processes or defense systems within 10 to 15 years.

Table A–2. Criteria For Selection of Critical Technologies

	CRITERIA	DESCRIPTION
National Needs	Industrial Competitiveness	Technologies that improve U.S. competitiveness in world markets through new product introduction and improvements in the cost, quality, and performance of existing products
	National Defense	Technologies that have an important impact on U.S. national defense through improvements in performance, cost, reliability, or producibility of defense systems
	Energy Security	Technologies that reduce dependence on foreign sources, lower energy costs, or improve energy efficiency
	Quality of Life	Ability to make strong contributions to health, human welfare, and the environment, both domestically and worldwide
Importance/Criticality	Opportunity to Lead Market	Ability to exert and sustain national leadership in a technology that is of paramount importance to the economy or national defense
	Performance/Quality/Productivity Improvement	Ability to cause revolutionary or evolutionary improvements over current products or processes, in turn leading to economic or national defense benefits
	Leverage	Potential that government R&D investment will stimulate private sector investment in commercialization, or likelihood that success in the technology will stimulate success in other technologies, products, or markets
Market Size/Diversity	Vulnerability	Potentially serious damage may be caused if a technology is held exclusively by other countries, and not the United States
	Enabling/Pervasive	Technology forms the foundation for many other technologies, or exhibits strong linkages to many segments of the economy
	Size of Ultimate Market	Ability to exert a major economic impact through the expansion of existing markets, creation of new industries, generation of capital, or creation of employment opportunities

APPENDIX B

ACKNOWLEDGEMENTS

APPENDIX B

ACKNOWLEDGEMENTS

The National Critical Technologies Panel gratefully acknowledges the contributions throughout this process of Everet H. Beckner (Department of Energy), John W. Lyons (National Institute of Standards and Technology), William H. Tallent (Department of Agriculture), John A. White (National Science Foundation), and Leo Young (Department of Defense), as well as Jules Blake, James G. Ling, Thomas J. Russell, Eugene Wong, and Ronald E. York (Office of Science and Technology Policy). The Panel also wishes to acknowledge the contributions of the staffs of the following organizations in preparing this report.

Private Sector

Aerospace Industries Association, National Center for Advanced Technologies

American Society of Mechanical Engineers

Computer Systems Policy Project

Council on Competitiveness

Institute of Medicine

National Academy of Engineering

National Academy of Sciences

Society of Automotive Engineers

SRI International

Federal Government

Department of Agriculture, Agricultural Research Service

Department of Commerce, National Institute of Standards and Technology

- Office of the Director
- Chemical Science and Technology Laboratory
- Computer Systems Laboratory
- Computing and Applied Mathematics Laboratory
- Electronics and Electrical Engineering Laboratory
- Manufacturing Engineering Laboratory
- Materials Science and Engineering Laboratory

Department of Defense

- Office of the Director of Defense Research and Engineering
- Office of Industrial Base Assessment (OASD/P&L)
- Air Force Manufacturing Technology Directorate
- Naval Research Laboratory, Center for Bio/Molecular Science and Engineering

Department of Energy

- Headquarters
- Argonne National Laboratory
- Brookhaven National Laboratory
- Idaho National Engineering Laboratory
- Lawrence Berkeley Laboratory
- Lawrence Livermore National Laboratory
- Los Alamos National Laboratory
- Oak Ridge National Laboratory
- Sandia National Laboratory

Department of Health and Human Services, National Institutes of Health

- National Institute of General Medical Sciences
- National Center for Research Resources, Biomedical Engineering and Instrumentation Program

Department of Transportation

- Research and Special Programs Administration
- Federal Highway Administration

Council on Environmental Quality

Environmental Protection Agency, Headquarters

National Aeronautics and Space Administration, Headquarters

National Science Foundation

Office of Science and Technology Policy

Office of Technology Assessment

Support Contractor

TASC

STATEMENT BY WILLIAM D. PHILLIPS

Chairman, National Critical Technologies Panel

Before the Subcommittee on Defense Industry and Technology
Armed Services Committee
United States Senate

From Roger Porter

April 25, 1991

STATEMENT
by
William D. Phillips
Chairman, National Critical Technologies Panel
Before the Subcommittee on Defense Industry and Technology
Armed Services Committee
United States Senate

Mr. Chairman:

Thank you for giving me the opportunity to present the report of the National Critical Technologies Panel. I am here today in my capacity as Chairman of the Panel, and the views I will express represent those of the Panel. You have a copy of the report, so I will not repeat much of the detail in it. However, I would like to expand a little on the background, methodology, and philosophy that underlie the final list of critical technologies set forth by the Panel. I will also briefly compare the list with those issued by the Department of Defense, Department of Commerce, and private sector Council on Competitiveness.

National Critical Technologies Panel

The National Critical Technologies Panel was appointed in 1990 in accordance with the Defense Authorization Act for Fiscal Year 1990. Seven of the 13 Panel members were from the Federal government, and the Department of Defense, Department of Energy, Department of Commerce, and National Aeronautics and Space Administration were specified by the Act to have representation. The remaining nine members, three from government and six from the private sector, were appointed by the Director, Office of Science and Technology Policy (OSTP).

In appointing these nine members, OSTP tried to achieve a wide representation of expertise and experience, bearing in mind that the study was focused on technologies "essential for the long-term national security and economic prosperity of the United States." We were fortunate to have the private sector represented by Dr. Robert W. Lucky, an expert in electronics, information, and communications from AT&T Bell Laboratories; Dr. Richard C. Messinger from Cincinnati Milacron, an expert in manufacturing and machine tools; Dr. Alexander Rich, renowned researcher in molecular biology and professor of biophysics at M.I.T.; Dr. Charles V. Shank, Director of the Department of Energy's Lawrence Berkeley Laboratory and an expert in optics and electronics; Dr. Albert R.C. Westwood, Vice President for Research and Technology at Martin Marietta Company, one of the major U.S. aerospace corporations; and Mr. James Worsham, former President of Douglas Aircraft with wide experience in aviation and aircraft manufacturing. These Panel members brought with them invaluable knowledge, not just about technologies but also about broader issues of commercialization and competition in the international marketplace.

In addition, we were ably assisted by Panel members representing the National Science Foundation and National Institutes of Health. Although the specified size of the Panel precluded appointing experts in other fields of technology, we worked very closely with the Department of Agriculture, Department of Transportation and the National Institute of Standards and Technology to ensure that we had a wide perspective. This diverse representation, along with the charge from Congress, accounts for the broader range of the Panel's list of critical technologies than is seen in the Department of Commerce's list of emerging technologies or the Defense critical technologies.

We also made a point during the course of the study to talk to and receive briefings from a number of other groups, both in government and the private sector, who were looking at related issues. I would particularly like to mention the private sector Aerospace Industries Association, the Computer Systems Policy Project, and the Council on Competitiveness with which we had fruitful interactions. They were very generous in sharing their knowledge and insight with us. The Council on Competitiveness issued its latest report "Gaining New Ground: Technology Priorities for America's Future" last month. The report contains much in the way of thoughtful analysis, and I commend it to you as a document well worth reading.

Methodology

The National Critical Technologies Panel approached its task with the benefit of prior government studies that I have already mentioned: The Defense Critical Technologies Plan (issued annually beginning in 1989), and the Commerce Emerging Technologies report issued in 1990. We quickly realized that determining the level of aggregation at which the critical technologies should be presented was an important consideration. We could all agree on the general categories such as materials, manufacturing, biotechnology, and so forth. However, these categories were too broad to be useful. On the other hand, focusing on very specific technologies such as zone refining of silicon or magnetic bearing applications in high-speed machining would have resulted in a list that was much too long and not likely to be comprehensive.

Our choice, then, was to select categories that were more detailed than the major technology areas but which were groupings of related but more narrowly focused technologies. Thus, for example, Micro- and Nanofabrication represents a family of technologies which include lithography techniques, thin films, surface treatments, and microdevices. In a few cases, as in High-Performance Metals and Alloys, the Panel added subtitles (shown in parentheses) to delineate the technologies of interest within a very broad category.

I mention all this because the Panel found no perfect way to deal with the problem of aggregation. In the end it is a matter of judgment, choice, and consensus; and every expert group faced with the same issue will deal with it somewhat differently. You will see this when you look at the tables in our report that compare the Panel's critical technologies with those nominated by other groups. There is general agreement among all of them, taking into account the slightly different objectives and boundary conditions that each group operated with. Therefore, as a practical matter it is best to concentrate on the overall message of these reports rather than get bogged down in the minutiae of methodology and taxonomies.

We were guided in our final selection by the following considerations:

- National needs
  - Does it contribute to U.S. competitiveness in world markets?
  - Does it enhance national defense?
  - Does it help our energy security?
  - Does it improve our quality of life?

- **Importance/Criticality**
  - -- **Does it give us an opportunity to lead the market?**
  - -- **Will it lead to improvements in performance, quality, or productivity?**
  - -- **Does it provide leverage to stimulate success in other technologies?**
  - -- **Will the U.S. be vulnerable to damage if the technology is held exclusively by another country?**

- **Market Size/Diversity**
  - -- **Does it form the foundation for many other technologies?**
  - -- **Will it exert a major economic impact?**

I realize that there are varying degrees of overlap among these criteria, but they were employed as guides, not as absolute figures of merit. As has been the case in related studies, the Panel was able to agree on a final compilation of technologies without necessarily agreeing completely on definitions or on the relative importance of various criteria.

Critical Technologies

The final list of 22 critical technologies selected by the National Critical Technologies Panel is:

MATERIALS

- Materials synthesis and processing
- Electronic and photonic materials
- Ceramics
- Composites
- High-performance metals and alloys

MANUFACTURING

- Flexible computer integrated manufacturing
- Intelligent processing equipment
- Micro- and nanofabrication
- Systems management technologies

INFORMATION AND COMMUNICATIONS

- Software
- Microelectronics and optoelectronics
- High-performance computing and networking
- High-definition imaging and displays
- Sensors and signal processing
- Data storage and peripherals
- Computer simulation and modeling

BIOTECHNOLOGY AND LIFE SCIENCES

- Applied molecular biology
- Medical technology

AERONAUTICS AND SURFACE TRANSPORTATION

- Aeronautics
- Surface transportation technologies

ENERGY AND ENVIRONMENT

- Energy technologies
- Pollution minimization, remediation, and waste management

The order in which the technologies are listed does not reflect a prioritization. In fact, the interesting feature of technologies today is that they are all interrelated. For example, continuing advances in computer software are necessary to support development of advanced capabilities in simulation and modeling, high-performance computing, and intelligent processing equipment. The only distinction on the list is between the first three general categories, Materials, Manufacturing, and Information and Communications, and the last three. The first three can be considered as "building blocks" for virtually all sectors of the economy. The other three categories are more akin to major areas of applications. However, all 22 technologies are critical to future U.S. national security and/or economic well-being.

You will note that the Panel did not include technologies that will only be realized in the longer term, such as nuclear fusion. We also excluded technologies associated specifically with space exploration because they had insufficient direct impact on national security and economic prosperity. The Panel did recognize, however, that space exploration will continue to stimulate advances in many of the critical technologies.

We included in our Panel's report a comparison between our critical technologies and those selected by Commerce, Defense, and the Council on Competitiveness. As I mentioned earlier, there is general agreement among them, allowing for slight differences in criteria, levels of aggregation, and definitions. I think the point to be made here is that knowledgeable people confronted with this task can generally agree on which technologies are critical. The real challenge we face is not generating a list but doing something about it. Also, the considerable overlap between technologies that are critical to both national security and economic prosperity attest to the importance and pervasiveness of these technologies in our lives today.

Implications

The key point that the Panel wants to emphasize is that technology alone cannot ensure national security and economic prosperity. Technology can make an important contribution to the future of U.S. national interests, but only if we learn to utilize it more effectively.

The Panel believes that the U.S. science base is unmatched in the world today. Science is the wellspring from which all technology is derived, and our broad scientific base allows us to generate technology in abundance. Support for the basic sciences needs to be broadly based in order to maximize the yield of useful advances. In contrast, technology development and deployment, because of the time and resource commitments involved, require greater selectivity and concentration of resources than is appropriate for the basic sciences.

However, in an environment of intensifying global competition, it is not enough to come up with new ideas, or even to develop those ideas into new technologies. The ultimate payoff comes when technologies are deployed, whether for military or commercial purposes. In the commercial world, successful firms are not necessarily the discoverers and developers of the latest innovation, but those that are able to swiftly bring the associated products to market. Those firms must also maximize profits in order to sustain through reinvestment a continuing flow of both new and improved products derived from research and development. Therefore, it is not the identification of critical technologies nor even the development of those technologies that is important; it is what we do with them that matters.

Future U.S. competitive success requires a fundamental change in the way U.S. industry competes in the marketplace. Our research institutions and businesses must place greater emphasis on deployment of new technologies. Furthermore, discovery, development, and deployment must be integrated and viewed as concurrent rather than sequential activities. As one of our Panel members expressed it: " U.S. industry must be infused, from the boardroom to the factory floor, with a relentless desire to constantly improve both product and production methods."

With that in mind, the Panel placed special emphasis on technologies related to the creation of new products and on the processes to make them. It is essential in today's competitive environment to take an integrated approach to manufacturing process and product design, performance, quality and cost. This integrated approach applies both to defense as well as commercial sectors of the economy.

Finally, the Panel recognized the importance of science and mathematics education to the nation's ability to remain a world leader in technology and technology application. Our ability to reap the benefits of the National Critical Technologies will depend on the generation of a technically literate workforce that possesses the skills necessary to develop and master these and future technologies.

Where do we go from here? As I have emphasized, our focus should not be on continuing to generate new lists, which all say about the same thing, but on doing something to improve the U.S. position. The Panel did not address implementation, but the Critical Technology Institute which is in the process of being established under the Fiscal Year 1991 Defense Authorization Act will be concerned primarily with follow-up on the Panel's report. We need to have a better understanding of overseas models in order to assess the nature of the competition. The value of research and development consortiums needs to be assessed, and the role of Federal laboratories should be examined. We also need to examine regulatory barriers, the limited available pool of capital, and other inhibiting factors that may be affecting our ability to compete internationally.

In conclusion, I believe that the primary benefit of doing this study has been to emphasize not only the importance of certain technologies but to highlight the fact that technology alone cannot ensure economic prosperity and national security. It can make an important contribution, but only if we learn to use it more effectively in developing innovative, high-quality, cost-competitive products and bringing those products to market in a timely manner. To do so will require, above all, continuing evolution in our approach to international economic competition.

MJB -
Ken Yale handed this to me at 6:35 pm. Dick has a copy as well.
- HGB

Proposed Letter to the Editor, Wall Street Journal

On April 25, 1991, the National Critical Technologies Panel presented to Congress a report describing 22 technologies considered critical for national security and economic prosperity. Since then a number of articles (e.g., Bob Davis, WSJ 5/13/91) appearing in the news media have drawn certain inferences regarding the Administration's current policy toward Federal support of technology development. In actuality, the Administration's policy has been consistent and was stated by President Bush in March 1990 when he said to the American Electronics Association: "This administration is committed to working with you in the critical precompetitive development stage where the basic discoveries are converted into generic technologies that support both our economic competitiveness and our national security. Here again we can help to level the international playing field on which you compete." This position was reiterated in the report "U.S. Technology Policy" which was issued in September 1990. This Administration report addressed a broader range of considerations and included the private sector's role, government incentives for the private sector, education and training, transfer of Federally funded technology, and Federal-State activities as well as Federal R&D responsibilities. Under the latter, the Federal government is considered to be responsible for participating with the private sector in precompetitive research on generic, enabling technologies that have the potential to contribute to a broad range of government and commercial applications.

The National Critical Technologies Panel was created in response to legislation passed in 1990 and sponsored primarily by the Senate Armed Services Committee. It was an independent technical panel consisting of seven government and six private sector members. The panel made it clear in their report that they had responded to the Congressional mandate, but that the important task was not as much to identify critical technologies as it was to get on with the job of deploying technologies for U.S. advantage. The Panel made no recommendations but simply noted that the U.S. (which includes the private as well as the public sector) has to place greater emphasis on the imaginative exploitation of its vast knowledge base.

On the same day that the National Critical Technologies Panel made its report, the President's Council on Competitiveness issued the enclosed fact sheet which summarizes Administration policies in support of technology development in America. It covers the same range of topics as the Technology Policy paper but with more detail on the legal and regulatory climate. Like the Technology Policy paper, the fact sheet was broadly reviewed within the Administration and represents a consensus view.

The aggregate message represented by these policy statements is very clear: The Administration is committed to enhancing the quality of life for all Americans, economic competitiveness, and national security; and it will do so by working with the private sector and facilitating the private sector's ability to perform. All elements of our society must recognize that we possess many strengths and assets that can be mobilized within our basic system of free enterprise - which is our Nation's ultimate strength.

Edited

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20506

Date: April 26, 1991

TO: Michael Boskin

FROM: **KENNETH P. YALE** KY
Chief of Staff

I had a good conversation with your staffer, Harry Broadman, about the recently released Critical Technologies Report.

I understand there may have been some confusion regarding the review and release of the report, and I would like to work with you to ensure that no such problems occur in the future. In addition, I would like to obtain your thoughts on any future activities involving issues raised by this report.

Attached is a copy of a draft statement we considered releasing to assist in clarifying the issues raised at the report's release. Because we have not received any press inquiries, we will probably hold off on the release of the statement.

Please feel free to call if you have any questions.

Thank you.

cc: Harry Broadman

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Thank you.

cc: Harry Broadman

DRAFT DRAFT DRAFT
STATEMENT BY DR. D. ALLAN BROMLEY
ON THE REPORT OF THE
NATIONAL CRITICAL TECHNOLOGIES PANEL
APRIL 26, 1991

The report of the National Critical Technologies Panel, formally released yesterday, was mandated by Congress in the Fiscal Year 1990 Defense Authorization Act. Under the legislation, the Director of the Office of Science and Technology Policy is required to appoint a panel solely for the purpose of developing the report.

I appointed Dr. William D. Phillips, the Associate Director for Industrial Technology of the Office of Science and Technology Policy as the panel chairman. The panel is an independent group of public and private sector members who are responsible for technology development and application.

The report sets forth the panel's interest in and concerns about certain key critical technologies. The panel has expressed its views, which will be reviewed by the Administration in its discussions of science and technology issues. This and other documents provide useful information that can assist in the further development of comprehensive national technology policies.

04/26/91

WASH. POST: 02-15-91

MICHAEL SCHRAGE

54/166

Industrial Policy by Another Name: Allan Bromley's Success as Science Adviser

As a nuclear physicist, "spin control" was the sort of phenomenon that D. Allan Bromley explored in papers like "Enhanced E1 Deexcitations in Ra-128 and the Evolution of Reflection Symmetry at Moderate Spins."

As Bush's White House science adviser, Bromley's science of spin control is less Einsteinian than Darmanesque. In fact, Bromley—a feisty, bow-tied Yale University professor—is probably as gifted putting clever twists and spins on administration policy initiatives as he ever was shooting ions down linear accelerators. He persuasively pushed for increased federal funding of scientific research; science was one of the few big winners in the Bush budget.

But, more intriguingly, he's also used his position as the head of the Office of Science and Technology Policy to call for government intervention in what he calls "critical technologies" to boost U.S. competitiveness in global markets.

Practically speaking, Bromley is now the highest-ranking administration official advocating both national—and nationalistic—policies to enhance America's technology leadership. He may be the science adviser to the president, but he is intensely involved in blending public-sector science with private-sector participation. Indeed, he argues that the best way to serve the president's interests is to create new dimensions of public-private relationships.

"Competitiveness and national security aren't separated anymore," says Bromley, asserting that the success of America's high-tech weaponry in the Persian Gulf has prompted a positive "sea change in attitude" toward technology. "The two are intertwined and have to be treated that way."

Doesn't that sound suspiciously like "industrial policy"—the anti-free-market concept that the John H. Sununus and Richard G. Darmans have sworn to expunge from the administration lexicon? Absolutely not, Bromley insists, it's really "pre-competitive generic technologies" like high-performance computer networks and new materials.

Excuse me, pre-competitive generic technologies? While Bromley doesn't quite wink when he describes such industrial pol—excuse me, generic technologies—you would swear there's a twinkle in his eye. Just slip a controversial industrial policy initiative like, say, high-definition television, into the Bromley Spin Vortex and it's deconstructed into tidy, fundable bundles of generic technology.

"I think the HDTV initiative [which was ultimately torpedoed by the White House] was presented in a completely wrong fashion," says Bromley. "It should have been presented as a package of generic technologies: high resolution imaging systems, application specific integrated circuits [i.e., custom computer chips] and frontier software . . . technologies that have broad applications throughout the economy. Instead, this was presented as a television problem."

As Bromley freely acknowledges, "there's a gray area" where some technologies are less generic than others. Then again, that doesn't seem to be as important as prodding people into building new technological infrastructures that can have a national impact.

Bromley is consequently a huge supporter of "high-performance computer networks"—a system that would do for high-speed, graphics-rich computer communication tomorrow what the telephone does for voice communications today. "Ten years from now," says Bromley, "I'd like it to be widely available and looked upon like the telephone network."

This new communications infrastructure—which has also been championed by Sen. Albert Gore Jr. (D-Tenn.), among others—would offer a vast array of new opportunities for American businesses to share information with each other, thus making them more competitive, Bromley hopes.

He feels so strongly about this that insiders indicate he will ask the Justice Department to seek an antitrust waiver for the giant regional phone companies to let them participate in building these new networks. "It's extremely important to take advantage of all the expertise we have," says Bromley.

But given Japan's dominance in computer chips and other telecommunications components, wouldn't this new American network have to be assembled from foreign parts?

"I don't think so," asserts Bromley. "We still have the leadership in hardware and software." In fact, he wants this network to be an American effort using American companies.

Bromley takes much the same perspective in his efforts to open up the national labs to better collaborate with American business. "We support the national labs, but too often they're doing things just to satisfy their own curiosity," he remarks. "We need to get people from industry much more involved in decisions that are now entirely internal. We want industrial collaborators to be present at the creation of new ideas and directions."

So should a Sony Corp., a Hitachi Ltd. or a Siemens AG be able to participate in the newly formed Lawrence Livermore industrial council? "I would probably say no," Bromley says. "The element of time is why . . . a six-month advantage can be critical."

Make no mistake, Allan Bromley may not have a huge budget, but he has a lot of influence and an agenda to go with it. Bromley is "wonderful, profane, vigorous and blunt," says Bruce Smith, a senior science policy scholar at the Brookings Institution who has known him for over 15 years. "But he's also a shrewd and cautious guy."

While Bromley is not an administration heavyweight like Sununu or Darman, he picks his battles carefully and is widely regarded as a credible team player. He has also enjoyed some success at mobilizing resources throughout the Office of Management and Budget and other executive departments.

By any fair measure, the Bush administration and Bromley have treated science and technology seriously in both policy and budget circles. What's not yet clear is just how far the administration is prepared to go. Without question, Bromley's efforts at semantic engineering have gone over well thus far. Will they continue to succeed when some of these initiatives harden into reality?

Can Bromley's brand of techno-nationalism survive and flourish in the Bush White House? To the extent that free-market ideologues dominate the White House, Bromley is playing a dangerous game. To the extent that George Bush believes government has to play an increasing role—however ill-defined—in sharpening America's technical edge, Allan Bromley is now the point man. We'll know by the end of the year.

Michael Schrage is a columnist for the Los Angeles Times.

WASH.POST: 01-31-91

Data Network Funding May Be First Step Toward U.S. 'Technology Policy'

54

By Evelyn Richards
Washington Post Staff Writer

The White House appeared to signal this week that the administration will provide funding in its new budget for initial development of a nationwide data network that would connect thousands of universities and companies throughout the country on a sort of superhighway for information.

As envisioned, the network would allow information to be exchanged at the rate of 50,000 single-spaced typed pages a second—at least 1,000 times faster than all but a few of the data networks in use today. In order to achieve such speeds, new techniques must be developed for, among other things, more rapidly routing information to the proper destinations and sorting out real data from garble.

Technology experts say a commitment to the data network, though relatively modest monetarily, would be a sign that administration policy is making a subtle shift toward endorsing at least a limited government role in bolstering the nation's industrial competitiveness by directing money to key technology projects.

Supporters of the network say the faster swapping of information and the use of high-speed supercomputers would help scientists more efficiently solve complex problems in dozens of fields, including biology, weather forecasting and speech recognition.

With some initial government funding to jump-start the project, supporters say, private companies are likely to expand the network, perhaps laying fiber-optic cables that could ultimately carry huge amounts of data to millions of businesses and homes. Government backing "will encourage the private sector . . . to develop these communication networks so they apply ultimately to every school, to every home," said Rep. George Brown (D-Calif.), chairman of the House subcommittee on science, research and technology.

Backers are hopeful that the budget, due to be delivered to Congress on Monday, will allot $150 million to a supercomputing initiative, which would include the network. That would be in addition to about $500 million the government already spends annually on similar research. Funding would span the National Science Foundation, the Defense Advanced Research Projects Agency, the Department of Energy, the National Aeronautics and Space Administration and other agencies.

The effort is part of what President Bush termed in his State of the Union message his proposal for "record" federal investment in research and development. In addition to high-performance computing, an apparent reference to the network and other supercomputing research, the White House said it will boost research funding for "generic" technologies, like advanced manufacturing and materials, whose fruits can aid numerous industries.

Early on, Bush's top advisers turned a cold shoulder to any government support of specific technology projects, contending that such backing would be an attempt to pick winners and losers in industry, something it said was better left to free enterprise.

Now, observers point to cautiously worded statements by the president's chief science adviser, D. Allan Bromley, who has emerged as the chief proponent of government-industry efforts aimed at helping U.S. firms compete more effectively with large overseas consortia, a practice sometimes termed "industrial policy."

Saying "there was considerable confusion as to where the Bush administration stood," Bromley said in a recent interview that the White House now is willing to foster "generic, pre-competitive" technologies, meaning technologies before they are ready to be turned into products.

"We have been moving more and more in the direction of substantial involvement," Bromley said.

The Commerce Department, for example, intends to make the first grants to companies—or groups of companies—soon under its new Advanced Technology Program. Though the department had only $10 million to dispense in 1990, it received proposals for $125 million. Congress tripled the funding in this year's budget.

Similarly, the White House Office of Science and Technology Policy, Bromley said, may help bring companies together to jointly pursue the "critical technologies" that will be listed in an upcoming report. The office also recently published "U.S. Technology Policy," a document that raised eyebrows more for its title than its contents.

"The main significance is that it's an officially sanctioned word," said Kenneth Flamm, a Brookings Institution technology specialist. "As to what's in there, there's no specifics," said Flamm, who favors a federal pool of at least $100 million that would be risked on new technology ventures.

While Flamm thinks major U.S. firms are prodding the Bush administration into exerting a stronger hand in pursuing specific technologies, others in industry remain wary of federal involvement.

"By and large the Silicon Valley guys are still saying, 'Hands off,'" said Burton McMurtry, a California venture capitalist.

1991 SCIENCE & TECHNOLOGY POSTURE HEARING WITH THE DIRECTOR OF THE OFFICE OF SCIENCE AND TECHNOLOGY POLICY

HEARING

BEFORE THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY U.S. HOUSE OF REPRESENTATIVES

ONE HUNDRED SECOND CONGRESS

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progress of the budget and there is little time to really adjust to retain and regain the balance.

Let me then turn to an area in which I have particular interest; that is technology development. When I first came to my office, one of my first initiatives was to bring aboard a presidentially appointed, Senate confirmed associate director, a very distinguished individual, Dr. William Phillips, as my associate director for industrial technology, and in doing so I wanted to send a message, first, that we were going to raise the image of T in OSTP, and, secondly, that the Bush administration meant business in terms of using our technology to improve our economic competitiveness and our national security.

There are several initiatives in the budget that address this whole question of technology. Applied research and development in the Federal sphere falls into several broad categories. One is the applied R&D that is required to fulfill the missions of the various agencies—health, in energy, in national security, and space. Another is the question of generic technology, the kind of technology that has application very broadly across our society, where no one institution or organization has any guarantee of getting an adequate return to justify, in itself, the investment that is required to move that technology forward in competitive fashion, and so here the administration has made it very clear.

The President, in this past year, has spoken a number of times about the responsibility of the Federal Government, in working with our private sector and working with you in the Congress, to make sure that the results of our investment in research and development are exploited more effectively, more rapidly, more widely, to the benefit of our Nation.

One of the very important areas here that I mentioned earlier, Mr. Chairman, is that in high performance computing and communications. The President has proposed a 30 percent increase in the support of this field in recognition of the importance of not only making this new power available to many more people in the nation but also to retaining what is still U.S. leadership in this very important field.

Another important example, of course, is in energy technology, and at this time, in fact, Admiral Watkins and the President are presenting the National Energy Strategy. The budget has a number of new initiatives that are keyed to that strategy to provide alternatives to petroleum, to increase the efficiency of energy use, and to advance new technologies that can have a major impact on the way we produce and the way we use energy. We are suggesting a 34 percent increase in our investment in this work on energy-related technologies.

Another area that finally we are beginning to recognize in this Nation is vitally important but one that was forgotten for a number of years is manufacturing. Manufacturing does matter, and we are in the budget making provision for investment in that. We propose to invest over a billion dollars in fiscal year 1992. About half of that supports procurement needs of Federal agencies, but the other half is focused specifically on the development of generic technologies, technologies that will move this Nation forward in areas that we perhaps can not even imagine right now, and within the Department of Commerce the administration proposes a 15 percent increase for generic applied research and technology development.

Aeronautics, another area where we have led the world but where our leadership is in serious jeopardy, is an area of emphasis in this budget, a proposed increase of 13 percent.

In biotechnology, which I believe in the next few decades will play the role that the physics- and chemistry-based technologies played in the post-World War II period, we have an exciting frontier. The budget suggests a $4.1 billion allocation for that frontier. They are designed, again, to maintain what we still have as a leadership position but a leadership position that we could very easily lose.

And, finally, let me mention an area that is not related to a particular budget initiative, and that is the research and experimentation tax credit. In recent years, you in the Congress have extended this on an annual basis, and we are requesting this year that you consider making it permanent, and the reason for that is clearly that if an industry cannot plan on it being available for longer than a single year period, the advantage that is inherent in this legislation is not being fully realized, and so I would urge your consideration of the making of that credit permanent.

If I could then—and I must apologize, Mr. Chairman, I am taking longer than I had intended. I have very little more to say. I would like, before finishing, though, to mention one or two other items, with your permission.

One of the very important aspects of our work in technology and in applied research is the way that we choose to support that research and development. I am convinced that in order for us to be effective in the Federal Government, it is vitally important that we develop true partnerships, where we collaborate with the private sector and with universities. There has been much talk about that kind of partnership for as long as I can remember but not too much action, and I believe that we have now the attention of all sectors of the community, and, working together, I think we can make some real changes that will move this forward.

I think that Sematech, for example, charged with developing the manufacturing technologies that will move us into a totally new generation of semiconductor, is one example of the kind of activity that we in the U.S. can mount uniquely by bringing together the know-how, the technology, and the strength of our industrial sector to focus their attention to develop a critical mass and to compete with the best that the world can produce anywhere.

A second example in this same area is one related to the National Energy Strategy, and that is the new cooperative venture that has been set up by the Department of Energy, Ford, Chrysler, General Motors, a number of the battery manufacturers, to move us forward in an exciting frontier, that of electric vehicles, where we are within a factor of 2 of truly viable units.

In general, we have the opportunity, if we grasp it, to work together with our private sector companies, to develop strengths, to develop technologies, to use know-how that cannot be matched anywhere else on the planet. It is an opportunity to challenge, and it is one that we can easily miss.

Dr. BROMLEY. Let me begin, sir, by attempting to answer the question.

I think we have a very important role to play because, first of all, we have to recognize that we are now very firmly part of an international marketplace and that in the major countries with whom we compete the governments of those countries have forged very strong links with their industrial organizations and that together they put federal monies, industrial monies, sometimes all sorts of monies, into very focused, targeted programs to develop technologies that are going to be important in terms of economic competitiveness, and by doing that, they share the risk, they speed up the process, and they minimize the cost to the individual participant.

Now if we are going to compete in that international marketplace, it seems clear to me that we, too, must enable our competing companies to avoid having to reinvent the technological wheel, whatever it is, individually, in parallel, because under those circumstances we simply can not compete, and so I believe that the Federal Government has as its primary role that of a catalyst, that of bringing together a critical mass of the private sector—industries, groups interested in a particular area—working with them, working with universities to develop a really coherent, sensible plan to move the United States forward into a leadership position and, where necessary, the injection of Federal funding to help this program move forward.

Now there has been tremendous confusion as to where we are in technology policy and industrial policy, and let me try to sort that out just very briefly. On the one end of the spectrum is basic research. No one questions there that there is a major role for the Federal Government, because since one can not project where the returns come or when, no individual organization can afford to make the investment necessary.

I would submit, sir, that the same thing is true in the generic technology area, much more true now than it ever was before, and that up through the whole development of the technologies until you are ready to produce a product or a process in the marketplace, that we in the Federal Government have a role. I do not believe that we have a role in the marketplace itself—for example, in a particular industrial sector, picking a particular company for support as opposed to other companies in that sector—because, frankly, I do not think that we in the administration are any smarter or nearly as smart as the people in that sector who can make the decisions better than we can.

Mr. VALENTINE. Thank you.

Mr. Chairman, I heard the gong. Thank you very much.

The CHAIRMAN. Thank you, Mr. Valentine.

Mr. Rhodes, you are the next one on my list.

Mr. RHODES. Thank you, Mr. Chairman.

I do not know about virtue having its rewards, but, clearly, being early does.

Dr. Bromley, I join with my colleagues in my admiration for your testimony and for the administration's budget proposals on this subject, and I appreciate it, and I wanted to say that at the outset because I think I am going to take issue with you on one particular

STATEMENT
by
William D. Phillips
Chairman, National Critical Technologies Panel
Before the Subcommittee on Defense Industry and Technology
Armed Services Committee
United States Senate

Mr. Chairman:

Thank you for giving me the opportunity to present the report of the National Critical Technologies Panel. I am here today in my capacity as Chairman of the Panel, and the views I will express represent those of the Panel. You have a copy of the report, so I will not repeat much of the detail in it. However, I would like to expand a little on the background, methodology, and philosophy that underlie the final list of critical technologies set forth by the Panel. I will also briefly compare the list with those issued by the Department of Defense, Department of Commerce, and private sector Council on Competitiveness.

National Critical Technologies Panel

The National Critical Technologies Panel was appointed in 1990 in accordance with the Defense Authorization Act for Fiscal Year 1990. Seven of the 13 Panel members were from the Federal government, and the Department of Defense, Department of Energy, Department of Commerce, and National Aeronautics and Space Administration were specified by the Act to have representation. The remaining nine members, three from government and six from the private sector, were appointed by the Director, Office of Science and Technology Policy (OSTP).

impact on national security and economic prosperity. The Panel did recognize, however, that space exploration will continue to stimulate advances in many of the critical technologies.

We included in our Panel's report a comparison between our critical technologies and those selected by Commerce, Defense, and the Council on Competitiveness. As I mentioned earlier, there is general agreement among them, allowing for slight differences in criteria, levels of aggregation, and definitions. I think the point to be made here is that knowledgeable people confronted with this task can generally agree on which technologies are critical. The real challenge we face is not generating a list but doing something about it. Also, the considerable overlap between technologies that are critical to both national security and economic prosperity attest to the importance and pervasiveness of these technologies in our lives today.

Implications

The key point that the Panel wants to emphasize is that technology alone cannot ensure national security and economic prosperity. Technology can make an important contribution to the future of U.S. national interests, but only if we learn to utilize it more effectively.

The Panel believes that the U.S. science base is unmatched in the world today. Science is the wellspring from which all technology is derived, and our broad scientific base allows us to generate technology in abundance. Support for the basic sciences needs to be broadly based in order to maximize the yield of useful advances. In contrast, technology development and deployment, because of the time and resource commitments involved, require greater selectivity and concentration of resources than is appropriate for the basic sciences.

However, in an environment of intensifying global competition, it is not enough to come up with new ideas, or even to develop those ideas into new technologies. The ultimate payoff comes when technologies are deployed, whether for military or commercial purposes. In the commercial world, successful firms are not necessarily the discoverers and developers of the latest innovation, but those that are able to swiftly bring the associated products to market. Those firms must also maximize profits in order to sustain through reinvestment a continuing flow of both new and improved products derived from research and development. Therefore, it is not the identification of critical technologies nor even the development of those technologies that is important; it is what we do with them that matters.

Future U.S. competitive success requires a fundamental change in the way U.S. industry competes in the marketplace. Our research institutions and businesses must place greater emphasis on deployment of new technologies. Furthermore, discovery, development, and deployment must be integrated and viewed as concurrent rather than sequential activities. As one of our Panel members expressed it: " U.S. industry must be infused, from the boardroom to the factory floor, with a relentless desire to constantly improve both product and production methods."

With that in mind, the Panel placed special emphasis on technologies related to the creation of new products and on the processes to make them. It is essential in today's competitive environment to take an integrated approach to manufacturing process and product design, performance, quality and cost. This integrated approach applies both to defense as well as commercial sectors of the economy.

Finally, the Panel recognized the importance of science and mathematics education to the nation's ability to remain a world leader in technology and technology application. Our ability to reap the benefits of the National Critical Technologies will depend on the generation of a technically literate workforce that possesses the skills necessary to develop and master these and future technologies.

Where do we go from here? As I have emphasized, our focus should not be on continuing to generate new lists, which all say about the same thing, but on doing something to improve the U.S. position. The Panel did not address implementation, but the Critical Technology Institute which is in the process of being established under the Fiscal Year 1991 Defense Authorization Act will be concerned primarily with follow-up on the Panel's report. We need to have a better understanding of overseas models in order to assess the nature of the competition. The value of research and development consortiums needs to be assessed, and the role of Federal laboratories should be examined. We also need to examine regulatory barriers and other inhibiting factors that may be hindering our ability to compete internationally.

In conclusion, I believe that the primary benefit of doing this study has been emphasize not only the importance of certain technologies but to highlight the fact that technology alone cannot ensure economic prosperity and national security. It ca make an important contribution, but only if we learn to use it more effectively in developing innovative, high-quality, cost-competitive products and bringing those products to market in a timely manner. To do so will require, above all, continuing attitudinal changes in our approach to international economic competition.

from the Critical Technologies Panel Report

Discussions of this report should de-emphasize its "official" nature. Rather, the report should be described as one set of opinions, called for by Congress, which the private sector may wish to consider in making decisions on investment in research and development. In addition, the Administration should not embrace the assumptions of industrial policy advocates by treating the technologies identified in this report as "winners" and should instead make clear its continuing opposition to picking winners and losers.

Examples of troubling passages are given below:

(page 1) "The key to U.S. competitive success involves a fundamental change in the way U.S. industry competes in the marketplace. U.S. research institutions and businesses must place greater emphasis on deployment of new technologies. Moreover, discovery, development, and deployment must be integrated and viewed as concurrent rather than sequential activities."

(page 17) "Such efforts [referring to activities of the Japanese Optoelectronics Joint Research Laboratory], should they be successful, would have a direct impact on the health of the U.S. microelectronics and computer industries..."

(page 25) "Advanced composites therefore represent a key technology with profound implications for the economic prosperity...of the United States."

(page 27) "A comprehensive data base on the characteristics and performance of Al-Li alloys is needed to overcome the reluctance of airframe manufacturers to promote the widespread structural application of a largely unfamiliar material."

(page 33) "Continued competitiveness of U.S. manufacturing equipment producers will depend not only on their own actions, but on a "sea change" in management actions and investment practices at U.S. manufacturing enterprises."

(page 41) "It is impossible to maintain competitive manufacturing capabilities...without having indigenous access to a broad range of state-of-the-art equipment."

(page 67) "High-definition imaging and display technology is critical both because it is driving the state of the art for a number of other critical technologies and because it has the potential to become a major component of the electronics market throughout the world."

(page 68) "The potential market for high-definition and related products is enormous, amounting to tens of billions of dollars for direct applications and perhaps hundreds of billions of dollars for indirect impacts in other electronics markets."

(page 68) "The current status of this evolution does not bode well for the future competitiveness of the U.S. electronics industry.... Continued weakness of the Untied States in development and production of consumer electronics will become an increasing handicap to U.S. competitiveness in the other electronics sectors."

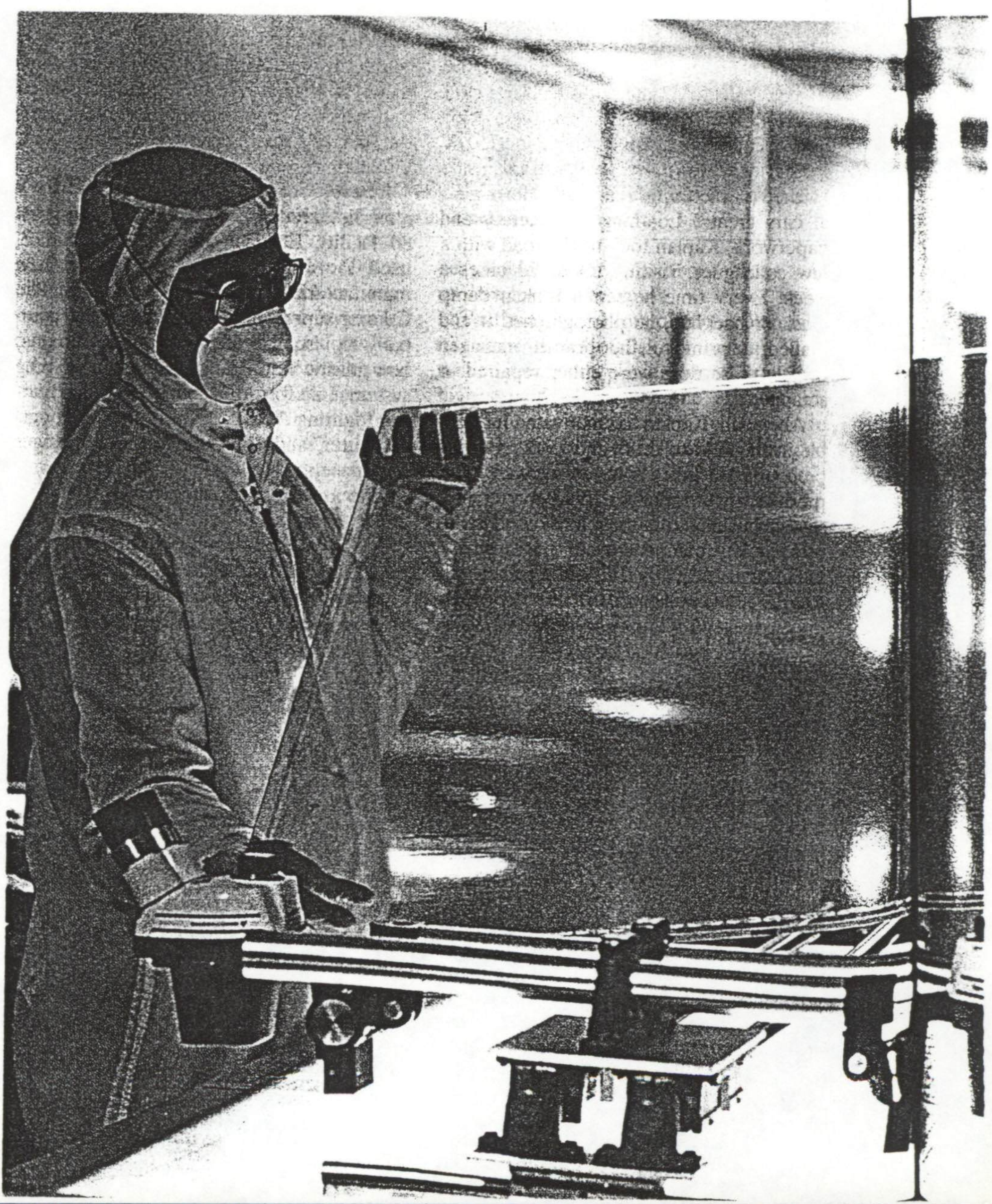
THE THAW IN WASHINGTON

There's a truce in the conflict between business and government. The White House is mapping out a partnership that stops short of heavy-handed industrial policy. ■ *by Edmund Faltermayer*

OH, TO BE a businessman in Japan or Germany. In those juggernauts, it's commonly said, government and industry collaborate over green tea and Rhine wine, with results that may yet reduce America to a hollowed-out branch-office backwater. As for the U.S., listen to CEO George Hatsopoulos of Thermo Electron, which operates in all three countries: "If anything, the U.S. government shows animosity toward industry." Or an economist from Munich at a recent symposium in Washington, who says he can't understand why the American political system "hates" corporations.

George Bush may be getting the message. His "technology policy" unveiled last September, the first ever from a U.S. President, aims to safeguard American industry's imperiled technological lead. Washington has traditionally poured its huge research and development budget ($67 billion this year) into defense, space, medicine, and basic science, including megaprojects designed to benefit all humanity—a superconducting supercollider, a human genome inventory, someday even a voyage to Mars.

Here on earth, companies in the commercial sector, including those with leading-edge technologies that generate good jobs, were on their own. But now the Administration is willing to sprinkle a little money on corporations and consortiums to determine whether new technologies can be turned into products. "In this way," the President said recently, "we can help leverage the R&D of the private sector, helping whole in-



The U.S. wants to nurture such technologies as high-definition flat-panel displays. That's a 60-inch monochrome screen at Photonics in Ohio, which also has a 19-inch color version.

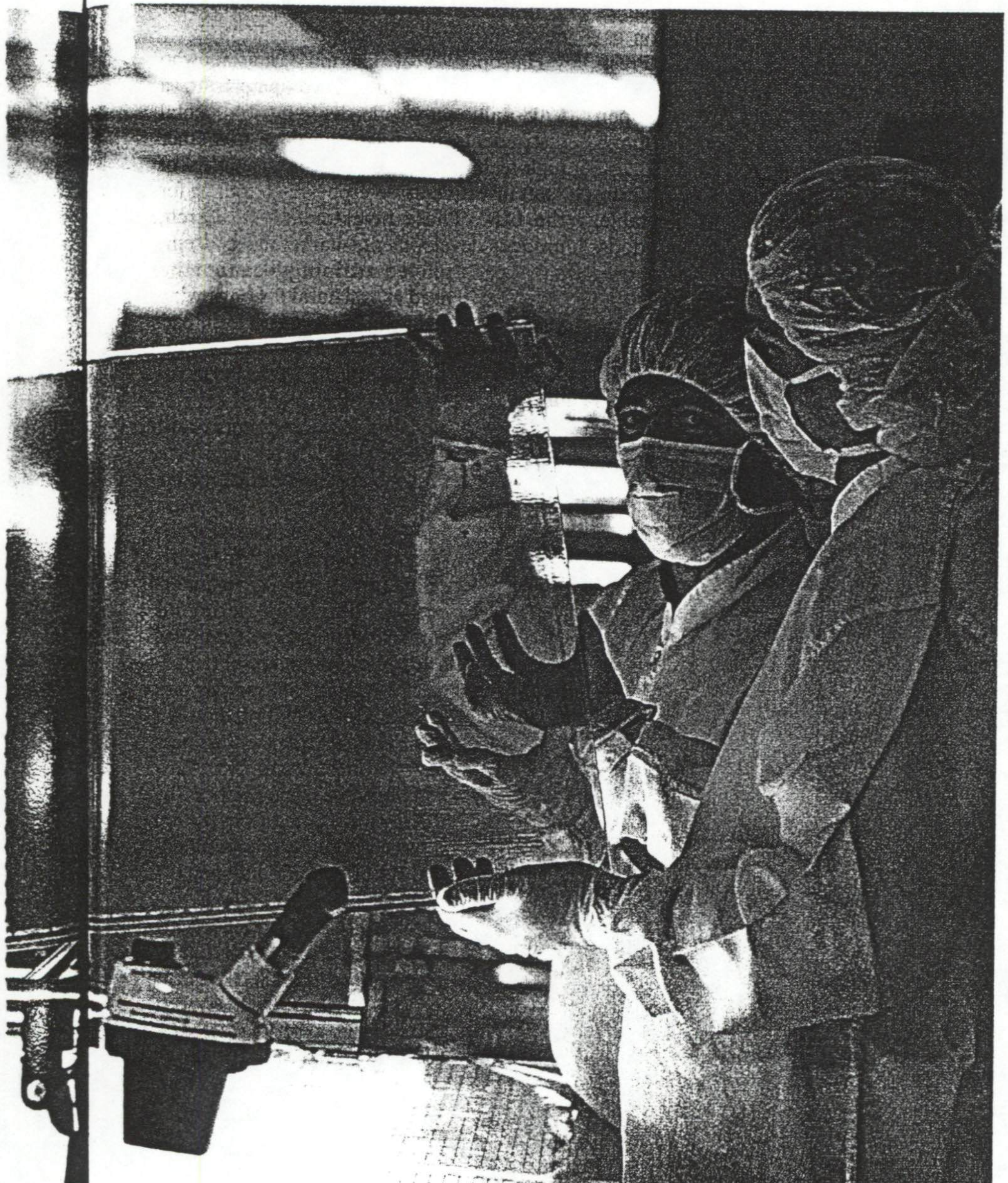
dustries advance in an increasingly competitive global market."

Can this be the same George Bush who recoiled from anything resembling industrial policy? The same Administration that torpedoed a proposal to help revive the consumer electronics industry? The same President whose chief economic adviser, Michael Boskin, used to say it makes no difference whether the country turns out computer chips or potato chips?

In words, at least, the Administration has crossed a divide. A special White House panel of experts from industry, academe, and government has just released a list of 22 technologies "essential to national defense as well as economic prosperity." Among them: composite materials, flexible computer-integrated manufacturing, and high-definition electronic displays. The list is meant to guide the Critical Technologies Institute, mandated last year by Congress and directed by D. Allan Bromley, assistant to the President for science and technology and mastermind of the new Bush policy. One of the institute's tasks, Bromley says: "To do long-range strategic planning, working very closely with the private sector to develop these technologies."

What induced the change? Concerned lawmakers played a part. So did industry-supported study groups that have raised more alarms about the nation's technological slide than a whole posse of Paul Reveres. Among them:

- The National Coalition for Advanced Manufacturing has called for a revived investment tax credit and "a major national effort" to make U.S. factories worldclass.
- The National Advisory Committee on Semiconductors (NACS) has characterized the problems facing U.S. chipmakers as "serious and growing worse." In a 1991 report it advocates federal help in creating high-volume electronics markets that would lift demand for American-made chips.
- The Computer Systems Policy Project, supported by 11 American computer makers, has urged Washington to shift its R&D spending to "technologies with known commercial relevance."
- The Council on Competitiveness, a coalition of CEOs, educators, and labor leaders, has called for government-supported "precompetitive" research by industry, just as the President now wants.



WASHINGTON, of course, has long maintained industrial policies for agriculture and housing. It has also supported R&D that helps commercial aviation. Heavy spending on medical science partly accounts for the strength of the U.S. pharmaceuticals industry. But in other areas America's Niagara of basic research, most of it freely available to the world, yields a comparative trickle of new American products.

It can take years to prove the practical usefulness of a discovery, such as high-temperature superconductors or the ability of light-sensitive crystals to store immense amounts of computer data in holographic form. U.S. corporations, goaded by Wall Street to keep earnings on the rise, are often loath to stay the course. So are startup companies. As a rule, unless their venture capital backers foresee handsome returns in a few years, nothing is ventured.

So why not put a dollop of government money in the neglected zone between pure research and product development? The principle of competition would not be compromised, because the object would be the development of "generic" or "enabling" technologies useful to several companies or industries. Rivals that normally battle for

REPORTER ASSOCIATES *Rosalind Klein Berlin and Alicia Hills Moore*

PHOTOGRAPH BY MICHAEL ABRAMSON

customers could collaborate peaceably until, as the Council on Competitiveness puts it, "technical uncertainties are sufficiently reduced to permit preliminary assessment of commercial potential." At that point, each participant would design its own widget and come out swinging.

That's how it has worked in Japan, where cooperative industrial research with government support helped spark successful global offensives in chips and computers. Europe is also on the consortium bandwagon (see table). Short of a world in which all governments agree to keep hands off civilian high-tech industries—an ideal still worth pursuing—the U.S. has little choice but to do likewise. Too many high-value-added North American jobs are at stake.

So is America's world leadership role. Amid the euphoria over operation Desert Storm, it has sunk in that most weapon innovations now feed off commercial R&D, not vice versa. In the 15 years it took to develop the Patriot missile, memory-chip makers raced through four product cycles. Says George Fisher, chairman of the Council on Competitiveness and CEO of Motorola: "Much of the electronics used in Gulf war weapons is not at the leading edge of technology today."

Serious implementation of Bush's new policy has yet to start. Senator Jeff Bingaman (D-New Mexico) complains that the Administration is still dragging its feet. Others see the seed of a sequoia-size boondoggle. Jeffrey Hamilton of Westford Technology Ventures, a New Jersey venture capital firm, trembles at how Congress might distort a technology policy: "They could micromanage and pork-barrel it to death."

A small-scale technology policy need not flout the principles of the free market. A resurrected Adam Smith would find little fault with the U.S. Commerce Department's Malcolm Baldrige quality awards, which cast government in the role of cheerleader and judge. Also beyond cavil are the Commerce Department's programs that disseminate technical wisdom to any manufacturer that asks.

At Kintz Plastics, a 90-person outfit in rural Howes Cave, New York, for example, cutting the molds for making such items as refrigerator shelves used to take eight weeks. With the help of experts from the government's Northeast Manufacturing Technology Center in Troy, 50 miles away, the company turned to CAD/CAM equipment—and telescoped mold-making time to ten days. The Troy center is one of five around the country, with more planned; meanwhile, technology-diffusion efforts by the states are far more extensive than Washington's (see box).

GOVERNMENT offers other kinds of help. The Bush Administration wants to liberalize a tax credit that rewards companies for increasing their R&D. Washington assists industry export drives, and the President strongly supports the efforts of Trade Representative Carla Hills to pry open closed markets around the globe. Approvingly, he calls her "tough as nails."

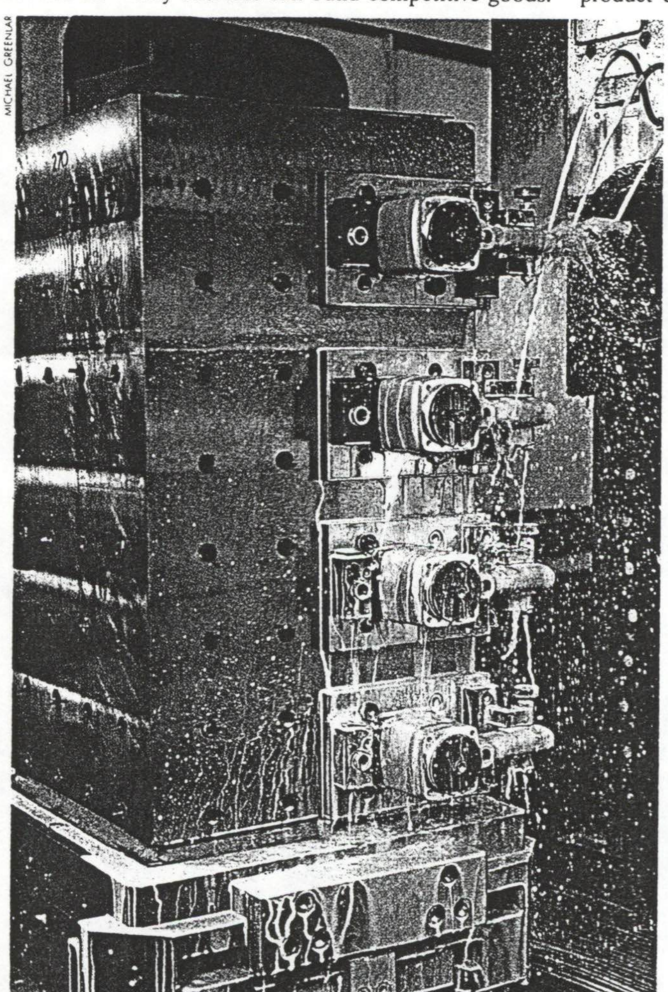
But while government can exhort, inform, deregulate, and pound the negotiating table, only business can build competitive goods. That takes capital, and the country needs far more of it. Nothing short of a White House–led crusade to promote saving, similar to Japan's campaign after World War II, will curb the nation's obsession with consumption.

And what a difference capital makes. During much of the Eighties, Chicago Pneumatic Tool Co. was milked to finance an acquisition spree. Then Sweden's Atlas Copco bought the company in 1987 and gave a green light to modernization. Says Chicago Pneumatic CEO Richard Besser of his overseas owners: "They're enlightened enough to say, 'If you can find the money, invest it.' Anything over the dividend requirement, we keep." At the company's plant at Utica, New York, productivity has doubled wherever new equipment has been installed.

Hatsopoulos of Thermo Electron, who built his Massachusetts company into a $708-million-a-year leader in environmental instruments, heart-assist devices, and other high-tech products, believes a dearth of "soft investments" is especially crippling for the U.S. These investments—research, product development, marketing, and employee training—cannot be used as collateral for borrowing and must be financed from corporate equity.

Since the Eighties, Hatsopoulos notes, increased flows of debt capital across borders have brought an "almost complete convergence" of real, after-tax interest rates among countries. But international flows of equity capital remain "insignificant," because stocks are inherently riskier than debt and equity investors prefer familiar companies on native soil.

The anemic U.S. savings rate is the main reason for the high equity costs American business faces, he contends. Just how high has been estimated by Robert McCauley and Steven Zimmer of the New York Federal Reserve Bank, in an analy-


MICHAEL GREENLAR

More companies need productivity-boosting equipment like this computerized installation at Chicago Pneumatic Tool in Utica, New York, which performs a series of operations on a batch of housings for air-powered tools. It's part of a $1 million machining center from Milwaukee's Kearney & Trecker.

sis based on adjusted price/earnings multiples in several countries' stock markets. In 1988, they calculated, the cost of equity was more than 12% in the U.S., vs. 7% in Germany and less than 6% in Japan. (The gap has narrowed, but most experts say it is still substantial.)

"If your competition has to make 6% or 8% but you have to make 12%, can you survive?" Hatsopoulos asks. Thermo Electron has because its P/E multiple is above the U.S. average. But in general, he argues, the high cost of equity dictates the short time horizons for which American managers have been maligned.

Hatsopoulos wants the savings rate to rise. He advocates cutting taxes on long-term capital gains, which he regards as an extra levy on retained earnings that raises the cost of equity. Long-term gains are tax-free in Germany and taxed only lightly in Japan. To avoid an immediate jolt to federal revenues, Hatsopoulos would apply the tax cut only to *future* gains on assets held at least five years from the day the law passes. That's quite a gesture from an entrepreneur who acquired most of his Thermo Electron stock at 30 cents a share and saw it grow 130-fold.

The Council on Competitiveness has a different solution to the capital problem: faster depreciation in "priority technologies." If any industry qualifies, it's chipmaking equipment, the initial link in the huge electronic industry's productive "food chain." With the rise of Japan's semiconductor industry, says G. Dan Hutcheson, president of VLSI Research in Silicon Valley, the U.S. share of the world market for chipmaking gear has fallen from 61% in 1985 to 45% in 1990. Michael Ciesinski of SEMI, the chipmaking equipment and materials trade association, adds that some companies with heavy R&D and expansion needs "are in desperate need of capital."

Bromley and other influential members of the Administration are sympathetic to the notion of faster write-offs, but the proposal highlights a major dilemma for the Bush Administration. By shrinking the federal deficit, it can free up capital for *all* business. But that will take time. "If you wait until the cost of capital goes down for the whole nation, you may wait forever," says CEO John Young of Hewlett-Packard. A selective tax policy that grants faster depreciation to, say, a half-dozen critical industries would limit the government's cost. But that puts Washington in the game of favoring some sectors over others.

In formulating the new technology policy, Bromley found an elegant way to traverse

BRAD MARKEL—GAMMA/LIAISON

White House aide Allan Bromley took the Bush Administration down a new policy path.

this ideological minefield. He has convinced the White House that it can plunge deeper into supporting key technologies without intervening in the market's selection of winners and losers. Once companies reach the point of competing with products and services, Bromley says, customers should decide the outcome.

Still out of bounds is a pet notion of industrial policy advocates: the use of government purchasing power to provide critical mass for new industries. "That begins to sound like command and control," says Bromley. In 1989 the White House shot down a Pentagon plan calling for military procurement programs to help spawn a civilian high-definition TV industry.

One object of the new technology policy, Bromley says, is to clear up "a fair amount of confusion as to where the Bush Administration really stands" in the wake of that fracas. The HDTV scheme was "unfortunately handled," he says. Had it been put forth not as "a specific application" called HDTV but as several generic technologies with broad potential—high-resolution displays, special integrated circuits, sophisticated software—the White House would have gone along. As it turns out, all three technologies are getting federal support at congressional insistence.

It all sounds reasonable—a pragmatic middle course as befits a pragmatic President. The proposed $76 billion federal R&D budget for fiscal 1992 would still overwhelmingly support defense, space, and medical research. The only major item related to industrial competitiveness is a $638 million request for research on high-performance

RESEARCH CONSORTIUMS: EVERYBODY'S GOT THEM

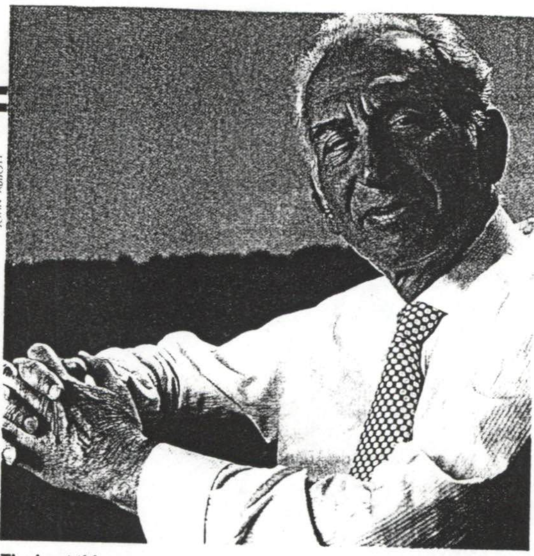
	ORGANIZATION	YEAR FORMED	BUDGET (% from gov't)	AREAS OF INVESTIGATION
U.S.	SEMATECH	1987	$200 million a year (50%)	Methods, materials, and equipment for making advanced semiconductors
U.S.	NATIONAL CENTER FOR MANUFACTURING SCIENCES (NCMS)	1986	$80 million a year (35%)	Improved machine tools, software, better machining methods, new materials
U.S.	MICROELECTRONICS & COMPUTER TECHNOLOGY CORP. (MCC)	1983	$60 million a year (10%–15%)	Advanced computing, software, computer-aided design, semiconductor packaging
JAPAN	ADVANCED TELEPHONY PROJECT	1986	$70 million a year (70%)	Hardware and software for telephones capable of translating languages
JAPAN	SYNCHROTRON ORBITAL RADIATION TECHNOLOGY CENTER (SORTEC)	1986	$15 million a year (70%)	X-ray lithography for advanced semiconductors; includes development of small atom smasher
JAPAN	OPTOELECTRONICS TECHNOLOGY RESEARCH CORP. (OTRC)	1986	$7.5 million a year (70%)	Optoelectronic parallel processor, ten-gigabit-per-second switch for communications networks
EUROPE	EUR. STRATEGIC PROGRAM FOR R&D IN INFORMATION TECHNOLOGY (ESPRIT II)	1987	$4.2 billion through 1992 (50%)	More than 400 projects in information technologies, microelectronics, computer-integrated mfg.
EUROPE	R&D IN ADVANCED COMMUNICATIONS IN EUROPE (RACE)	1987	$1.6 billion through 1992 (under 50%)	Integrated broad-band telecommunications network
EUROPE	EUROPEAN RESEARCH COOPERATION AGENCY (EUREKA)	1985	$8 billion committed (30%)	Encompasses 370 industrial technology projects, including a chip initiative called Jessi

FORTUNE TABLE / SOURCES: *IEEE SPECTRUM*, EUROPEAN COMMUNITY

Throughout the industrialized world, governments are banding together with corporations to develop commercially promising advanced technologies. In this sampler of consortiums, the heaviest spender is Europe, which is using them to play high-technology catch-up with the United States and Japan.

computing and a fiber-optic network that could become tomorrow's information superhighway.

Ian Ross, president of Bell Labs and chairman of NACS, complains that industrial competitiveness remains an "orphan" in the budget. But huge shifts in federal R&D spending may not be necessary. Since 1984, when Congress relaxed antitrust laws, rival companies in the same industry have felt freer to band together for precompetitive research. Often the economics are so compelling that no government help is needed. When it is, Washington wisely insists in most cases that industry put up at least half the money. Japan's Ministry of International Trade and Industry no longer doles out large sums for industrial research. Says Motorola's Fisher on Japan: "Government-sponsored consortiums don't so much do the research as spell out the direction."


JOHN ABBOTT

The best thing government can do, says Hatsopoulos of Thermo Electron, is spur saving and cut the tax on long-term gains.

Bromley has big hopes for consortiums in the U.S. Their members, he says, don't have to waste time and money by separately "reinventing the technological wheel." But pitfalls exist. In individualistic America, will companies share knowledge or withhold it? Corporations that have chosen to participate are betting that three important government-supported consortiums—for manufacturing, microelectronics, and chipmaking—can be made to pay off.

The 120 members of the National Center for Manufacturing Sciences (NCMS), in Ann Arbor, Michigan, range in size from General Motors to family-owned firms. Many projects are in machine tools where, in the words of consultant William Copeland of Stamford, Connecticut, "companies don't have fat, healthy profit margins to plow back into R&D." All the more remarkable, then, that one participant is a thriving toolmaker that would seem to have the least to gain from joint research.

Giddings & Lewis of Fond du Lac, Wisconsin, spent 10% of sales on R&D last year. "We're a light-year ahead of Germany" in software for flexible manufacturing systems and production cells, and "two light-years ahead of Japan," declares CEO Bill Fife. So why NCMS? Says Jim Simon, Giddings's vice president for engineering who attends the consortium's meetings: "We can't by ourselves keep pace with everything."

Founded in 1986, the consortium gets more than a third of its $80 million annual budget from the Air Force and parcels out all its research money to outside contractors. President Edward Miller expects the budget to ramp up to $500 million in the next five years. NCMS has already achieved some real breakthroughs, including a method for hardening cutting tools by coating them with diamond film.

THE MICROELECTRONICS & Computer Technology Corp. in Austin, Texas, was founded in 1983 partly as an answer to Japan's fifth-generation computer project. The $60-million-a-year organization has 57 participants, which can pick and choose among 34 projects; federal research contracts account for about 10% to 15% of the budget.

Nothing huge has come out of MCC. But members are pleased with some lesser developments already incorporated into computer-aided design programs, artificial intelligence systems, and "packaging" of semiconductors. By working with MCC, for example, 3M developed an improved method of "tape-automated bonding" for joining semiconductors to surrounding circuitry.

The most promising news about MCC is its new boss, Craig Fields, a whiz who formerly ran the Defense Advanced Research Projects Agency (Darpa). "I want MCC to be the best there is," says Fields, who talks at jet-plane speed. He prefers to undertake projects for their business impact rather than their technological effect. Some should be planned for "shorter time-bites," he says, because member companies' plans often change. And instead of always trying to win by a mile with big breakthroughs, Fields

NEW ASSISTANCE FROM THE STATES

★ States have long been notorious for the zero-sum game called smokestack chasing, in which they compete for factories by offering tax breaks and facilities. But the recession of 1982 brought something new: programs that boost the competitiveness of companies already on the scene and hatch new ones.

Such efforts accounted for a sizable chunk of the $550 million states spent on technology development in 1988. Companies generally pay at least half the cost of participating in the programs, which provide a variety of services: information about new manufacturing technology, links to university experts, "incubators" that offer reduced-cost factory and office space, and even seed money.

Pennsylvania's Ben Franklin Partnership, which operates four industry-university research consortiums, has created 765 new companies and helped 909 others expand since 1983. Any Georgia company can get up to five days of free manufacturing advice from any of 12 regional offices operated by Georgia Tech, a state school.

Steris Corp. of Painesville, Ohio, was born in 1987 after inventor Raymond Kralovic won a state grant to work with Case Western Reserve University in nearby Cleveland. He had an idea for quick sterilization of the delicate instruments used in new types of endoscopic surgery. Conventional sterilization took hours and required toxic gases. The Steris process does the job in 20 minutes using a proprietary chemical solution. The development money came from Ohio's Thomas Edison Program, which operates eight technology centers around the state.

The U.S. Commerce Department runs a clearinghouse on state programs (202-377-8100). To learn about those in your state, you can also consult its department of commerce or office of economic development.

says, MCC should "try to win by an inch, putting priority on process improvements that can get you that inch ahead in time to market, that inch ahead in price and quality, which lead to much more than an inch ahead in market share."

WASHINGTON, through Darpa, contributes $100 million a year to Sematech, a consortium of semiconductor manufacturers in Austin. Its 14 member companies match the grant dollar for dollar and lend talent. Robert Galvin, former chief of Motorola, recently became chairman.

One objective of the four-year-old consortium is to shore up the chipmaking equipment industry. CEO James Morgan of equipment maker Applied Materials says Sematech "has developed a much better working relationship between customers and suppliers." Several consortium members have placed big orders with American equipment makers, and Sematech CEO William Spencer, formerly at Xerox, asserts that without the consortium U.S. chipmakers "would have lost their equipment base."

Sematech's other goal is to develop reliable methods for making the world's most densely printed chips, thereby reaching parity with Japan. Spencer says he's confident the consortium can meet its target of 0.35-micron line widths by 1993, using made-in-America equipment at each critical step. That would allow members to manufacture an aspirin-size chip with a 64-megabit memory, an enormous jump from the one-megabit chips that are the standard today.

These consortiums are trying to put existing U.S. industries out front. Could judiciously awarded government grants lead to the creation of entirely new industries? That's one of the aims of the Commerce Department's closely watched Advanced Technology Program (ATP), which recently announced its first $9 million in grants to 11 consortiums, joint ventures, and individual companies. Among the precompetitive technologies to be supported are holographic memory systems, a handwriting-recognition system for computers, and better ways to make flat-panel displays.

These displays, used in laptop computers, are another U.S. technology that Japan has run with after giant American players gave up. Only niche companies survive, though they boast some superior techniques that could yet be incorporated into tomorrow's big-screen TV sets. Photonics Imaging, a member of a consortium receiving an ATP grant, sells big, high-resolution monochromatic screens using gas plasma technology to the armed services in the U.S., Britain, Germany, and Japan.

The ATP grant of $1.35 million to the consortium looks puny. Says Robert Costello, a former Defense Department official now at the Hudson Institute in Indianapolis, who has visited Hitachi, a big Japanese supplier of displays: "They spend far more for R&D in flat-panel displays in that one company than the whole ATP program."

Because of a cascade effect from industry matching and follow-up grants, the ATP's initial $9 million will trigger $100 million of research, and the program will grow. The National Institute of Standards and Technology (NIST), which administers it, will distribute $36 million next year. Any good idea the applicants come up with has a chance, says NIST director John Lyons: "We let *them* set the agenda.

Sad, but true: Distrust of Japan is one of the forces driving U.S. business and government together. A rational reason for closer ties, says George Heilmeier, head of Bellcore research labs, is to make sure U.S. companies are not dependent on overseas competitors for critical components.

This doesn't mean the U.S. should surround itself with a technological fence. Global tie-ups by business are an unstoppable trend. Bromley says that at some point the U.S. might want to share with other countries what's coming out of consortiums like Sematech. But he adds that in return, "we must be much more aggressive in seeing that we get something of comparable benefit." That sounds like a nation looking to its own interests—something Japan has done for years. ■

DOUG MILNER

Consortium research bears fruit in Texas: MCC's technique for automatically mating microchips to connecting circuits on a filmlike backing.

OFFICE OF SCIENCE AND TECHNOLOGY POLICY

SUMMARY OF COMMENTS ON "SCOPE DOCUMENT"

On July 31, 1990, the Office of Science and Technology Policy published for comment in the **Federal Register**, a document entitled, "Principles for Federal Oversight of Biotechnology: Planned Introduction Into the Environment of Organisms with Modified Hereditary Traits," (55 FR 31118). Forty letters of comment were received by the October 1, 1990 deadline; another four letters were received past this date. The following is a brief summary of these comments.

OVERVIEW

- General response to the "Scope Document" was positive--the Administration's effort to define a common basis for regulation of planned introductions was applauded.

- There was strong support for the principles outlined in the body of the document which emphasized a risk-based approach to regulation.

- The majority of criticisms focused on the **"Examples of Potential Exclusion Categories"** while other comments related to ensuring implementation of the principles through the regulatory process. Particular words or phrases were cited as vague or otherwise problematic.

SPECIFIC ISSUES

Risk-based Approach

- Thirty-two letters specifically noted the wisdom of a risk-based approach, particularly if the level of oversight is commensurate with the degree of potential risk.

- The **"Criteria for Evaluating Risk"** were deemed adequate and appropriate in that they focused on characteristics of the organism and the environment into which it is being released, rather than on the process by which the organism is produced.

- Several respondents stated that there is a sufficient body of scientific experience to support risk evaluation as a means for determining need for oversight.

Examples of Potential Exclusion Categories

- Several respondents supported the principle of categories of introductions that could be excluded from oversight as a move away from case-by-case regulatory review.

- The most frequent objection to the exclusion categories (10 letters) was that categories 1-5 were process-based, in contradiction with the principles contained in the body of the document. Thus, several respondents proposed deleting the

"Examples of Potential Exclusion Categories."

- At least 3 commenters were opposed to any regulatory scheme that did not include all of the exclusion categories on the premise that current regulatory inconsistencies and confusion would be retained otherwise.

- Others (5) suggested retaining category 6 as the cornerstone for policy on exemptions.

- It was pointed out that many organisms produced using methods described in categories 1-5 would be subsumed under category 6 if the resulting product posed greater risk to the target environment than the parental organism.

- Evidence was offered that organisms produced via methods proposed for possible exclusion may still pose health or environmental hazards and, thus, should not be exempted.

- One commenter felt that category 2 should be modified to cover only those exchanges "**known to occur in nature**" and another suggested adding **viruses**.

- There was a proposal to add "**organisms resulting from mutagenesis by transposable elements**" to category 5.

- A new category was proposed comprised of organisms developed using recombinant techniques (such as PCR, in vitro mutagenesis, homologous recombination, or other self-cloning methods) which result in phenotypes identical to those obtainable through traditional techniques.

- One letter suggested adding three organisms to the exempt list indicating interest in a process similar to that used by NIH whereby conditions under which certain experiments may be performed are considered by petition to the Recombinant DNA Advisory Committee.

Implementation

- A recurring theme was the need for consistent implementation across agencies. It was suggested that OSTP remain visible and involved in order to ensure interagency consistency.

- Three letters noted the past delays in proposing agency regulations and encouraged rapid implementation of the "Scope Document."

- Four commenters predicted that it would be difficult or impossible to implement this scheme because it was not clear who was responsible for determining the need for oversight.

- IBCs were proposed as a venue for preliminary determination of risk and need for further oversight.

- It was suggested (2) that notification be deleted from the description of oversight methods in order to allow for categories of exemption from other, more burdensome forms of oversight.

- Several respondents stated that a system of licenses or permits was not appropriate for research activities.

Definitions

- The most problematic word was **"similar"** when used to describe the situation in which "the level of risk of an introduction is the same as or less than a previous safe introduction." Suggested alternative language in 3 letters was "comparable to or less than."

- Two letters questioned the adoption of the term **"modified hereditary traits"** as opposed to "genetically modified organisms," which implies that modified traits are heritable, regardless of how the modification was achieved.

- There was a question as to whether or not contained field tests would be included under **"planned introductions into the environment."**

Additional Issues

- Four respondents proposed alternate schemes, three of which involved the development of lists of exempt organisms or introductions. Suggested criteria for inclusion on such a list were **"familiarity"** or inclusion on the list currently maintained by CDC and NIH.

- OSTP was reminded that this document will play an important role in international negotiations and product export.

L. A. Times
May 9, 1991

INNOVATION / MICHAEL SCHRAGE

Meaningless Lists of 'Critical' Technologies

Drawing inspiration from both Santa Claus and People magazine, the champions of competitiveness are making up lists and checking them twice.

These lists—generated with much fanfare by the good folks at the White House Office of Science and Technology Policy, the Commerce Department and the industry-based Council on Competitiveness, among others—are intended to show which technologies are naughty and nice. In other words, what are the 25 Most Intriguing Technologies? Where is the United States ahead and Japan behind? What is the Sexiest Technology Alive? Inquiring minds want to know.

They'll find no titillating technologies here. The National Critical Technologies Panel (mandated by Congress and appointed by White House Science Adviser D. Alan Bromley), for example, selected no fewer than 22 technologies "deemed critical to the national needs that have been identified." These included software, biotechnology, pollution minimization and remediation, high-definition imaging and displays, ceramics, composites and several other obvious candidates.

Come on! This is techno-pablum being served up as meaningful analysis. Saying that "software" is a critical technology is precisely like saying that physics is a critical science. It's true, but so what? Does listing software—or biotechnology or composites—as a critical technology give one any sense of how to prioritize research in the area? Does it offer any insights into the commercialization process? Does it send any kind of meaningful message to the investment community about how resources should be best allocated?

Of course not. What we have here is "information" that adds virtually nothing to the debate over the critical issues surrounding America's massive public and private investments in technology. Your tax dollars at work. (Calls to the chairman of the White House panel were not returned.)

By the way, don't think that it's simply a happy coincidence that federal funding for most of these "critical technologies" just happens to have been increased. These lists aren't just obvious; they're also politically correct. There's nothing challenging, counter-intuitive or provocative about them.

"I don't think these lists have any intrinsic merit at all," asserts Michael Odza, a technology transfer consultant and publisher of the Berkeley-based Technology Access Report. "They don't seem to change people's thinking in any way."

"In general, lists force people to give at least some level of priority," says Robert Costello, an undersecretary of defense in the Reagan Administration who championed using Pentagon procurement polices as a prod to industrial competitiveness. "But, if you don't explicitly link them to an action agenda, they're pretty marginal."

These lists are as marginal as they come. If you wanted to write something important, you wouldn't make a list of the nouns, verbs and adjectives you planned to use; you'd figure out what you really wanted to say. The problem here is that people are focusing on the technologies rather than on the economic, industrial, governmental and scientific processes that create them.

America isn't the undisputed global leader in software because the Defense Advanced Research Projects Agency, IBM and Microsoft sat around in their respective offices coming up with lists of critical systems software and applications to develop. This country dominates the field because it evolved the appropriate infrastructures of hardware, capital, academic research and entrepreneurs that stimulate state-of-the-art innovations.

Technology isn't a product. It's a process—but you'd never know it from scanning these lists.

"We never make up lists," says Michael C. Sekora, who once ran the Pentagon's Project Socrates technology planning support software and is now providing support to American technology firms as president of Florida-based Technology Strategic Planning. "Coming up with a list has no value. Instead of coming up with a list, you need a strategic plan."

Plans, don't begin with lists of "critical" technologies, says Sekora; they begin with an objective—"and then you figure out how you're going to effectively utilize worldwide technology to achieve that objective."

It's at that point that you begin to make the hard decisions about what technologies should be internally developed, externally acquired or jointly created with partners. Competitiveness comes from the ability to cost-effectively balance these different technology paths.

Needless to say, the various critical technologies lists barely touch the issue of cost-effectiveness. What price is America prepared to pay to be "competitive" in new materials and biotechnology? Will this price be borne by taxpayers? Or will innovative government policies put industry in a position to cost-effectively compete in global high-tech markets by better leveraging existing resources?

There's no way to know the answers to those questions because they aren't being asked. Instead of thought-provoking ideas, we're getting laundry lists of technological cliches. That's hardly shocking. But cliches do nothing to boost either our awareness or competitiveness. The real debate isn't about which technologies are economically important; it's about how best to manage those technologies to boost the quality of national life.

MJB - FYI - HGB

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20506

Date: April 26, 1991

TO: Michael Boskin

FROM: KENNETH P. YALE KY
Chief of Staff

I had a good conversation with your staffer, Harry Broadman, about the recently released Critical Technologies Report.

I understand there may have been some confusion regarding the review and release of the report, and I would like to work with you to ensure that no such problems occur in the future. In addition, I would like to obtain your thoughts on any future activities involving issues raised by this report.

Attached is a copy of a draft statement we considered releasing to assist in clarifying the issues raised at the report's release. Because we have not received any press inquiries, we will probably hold off on the release of the statement.

Please feel free to call if you have any questions.

Thank you.

cc: Harry Broadman

TO: FILE

Documents originally attached to following page.

DRAFT DRAFT DRAFT

STATEMENT BY DR. D. ALLAN BROMLEY
ON THE REPORT OF THE
NATIONAL CRITICAL TECHNOLOGIES PANEL
APRIL 26, 1991

The report of the National Critical Technologies Panel, formally released yesterday, was mandated by Congress in the Fiscal Year 1990 Defense Authorization Act. Under the legislation, the Director of the Office of Science and Technology Policy is required to appoint a panel solely for the purpose of developing the report.

I appointed Dr. William D. Phillips, the Associate Director for Industrial Technology of the Office of Science and Technology Policy as the panel chairman. The panel is an independent group of public and private sector members who are responsible for technology development and application.

The report sets forth the panel's interest in and concerns about certain key critical technologies. The panel has expressed its views, which will be reviewed by the Administration in its discussions of science and technology issues. This and other documents provide useful information that can assist in the further development of comprehensive national technology policies.

04/26/91

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLIC
WASHINGTON, D.C. 20506

DATE: 3/15/91

TO: Michael J. Boskin
ADDRESS: CEA

Telephone Number: 5042
Fax Number: 6947

FROM: Allan Bromley

Telephone Number: 7396
Fax Number: (202) 395-3719

Number of Pages (including cover sheet): 2

SPECIAL INSTRUCTIONS:

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20506

March 14, 1991

MEMORANDUM FOR DISTRIBUTION

FROM: D. ALLAN BROMLEY, DIRECTOR

SUBJECT: APPOINTMENT OF DR. PIERRE PERROLLE AS ASSISTANT DIRECTOR

It gives me great pleasure to inform you of my appointment of Dr. Pierre Perrolle as Assistant Director of the Office of Science and Technology Policy (OSTP). He serves in our Division of Policy and International Affairs, headed by OSTP Associate Director, Dr. J. Thomas Ratchford. Dr. Perrolle's primary responsibility will be for the social sciences. His mandate is to help ensure that appropriate persepectives and expertise from the social sciences are included in and brought to bear on the formulation of national science and technology policy, and to assist in the coordination of social science research across the Federal agencies.

Dr. Perrolle, a political scientist with special area expertise on China, has a distinguished record of Government service. He is a member of the Senior Executive Service and has held positions in the National Science Foundation's Division of International Programs since 1980. Dr. Perrolle has also served in the Senior Foreign Service as Counselor for Scientific and Technological Affairs at the U.S. Embassy in Beijing (1986-88). In the late 1970's he was on the senior staff of the Committee on Scholarly Communication with The People's Republic of China at the National Academy of Sciences. Prior to coming to Washington, Dr. Perrolle was on the faculty of Wheaton College in Massachusetts. He holds undergraduate and doctoral degrees in political science from MIT and Brown University, respectively.

I am confident that in his new position at OSTP Dr. Perrolle will both catalyze interagency coordination efforts and help ensure that the current and potential contributions of social science research are appropriately considered in the policy process. I know that you share with me support for these efforts.

Document originally attached to following page.

Circulate to John & Dick &
1 to me w/ memo from
Sir Alan

OSTP

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20506

March 21, 1990

MEMORANDUM FOR MICHAEL BOSKIN

FROM: James B. Wyngaarden, M.D. Jim Wyngaarden
Associate Director for Life Sciences

SUBJECT: Comments on Remarks by Mr. Robert Swanson, Chairman of the Board, Genentech

I was pleased that you were able to attend Bob Swanson's presentation on March 20, and I was interested in your comments highlighting Administration efforts that he had not had time to mention. One point you cited was the Administration's proposal to double the NSF budget in five years, which incidentally I strongly support. I was not sure whether that remark was intended to relate to the support of biotechnology research, or to science in general. But I thought I should mention that it is really NIH's sponsored research that has both created the biotech industry and nourished it.

The biotechnology industry is essentially a spin-off of NIH-sponsored research in genetics and immunology. About 80 percent of current federally supported research that relates to biotechnology and its science base is conducted through the NIH (Exhibit 1). The total basic science budget of the NIH is the largest of non-defense departments or agencies (Exhibit 2), yet in the Administrations' commitment to expanding basic science research, the NIH budget has not participated in parallel with most other science Departments. In fact if one subtracts out the AIDS and Human Genome initiatives at NIH, the request for the rest of the NIH increases only 3.7 percent this year. It is within that 3.7 percent increase that the bulk of the research relating to biotechnology is to be found.

I would hope that the same emphasis would be put on the life sciences as on the physical sciences, and that the Administration would propose the same order of increase for the basic NIH budget over the next five years that it has publicly requested for the budget of the NSF. Progress in the health sciences and preservation of our competitive position in biotechnology would be enhanced by such a development.

Attachments

cc: Mr. Richard Darman, OMB

EXHIBIT 1

TABLE 2

Federal Support for Biotechnology Research, 1989-1991

(current dollars in thousands)

Agency	FY 1989	FY 1990	FY 1991
National Institutes of Health	2,660	2,741	2,862
Alcohol, Drug Abuse, and Mental Health Administration	107	141	183
Department of Defense	129	122.6	126.6
National Science Foundation	119.5	124.5	129.5
Department of Agriculture	96.7	100.7	125
Department of Energy	80.1	92.5	115.3
Others	9.2	41.7	37.5
TOTAL	3,201.5	3,364.0	3,578.9

PRESIDENT REQUESTS INCREASES FOR BASIC RESEARCH IN FY 91

The Administration has requested increases in basic research spending for FY 91. Below is a chart of the President's request compared to FY 90 amounts. (Figures are in billions.)

(Note: the definition of basic research can vary dramatically from agency to agency and even within agency departments.)

	FY 90	President's request	
National Institutes of Health	4.256	4.499	5.7%
National Science Foundation	1.651	1.853	12.2
Department of Energy	1.750	1.939	10.8
NASA	1.462	1.823	24.7
Department of Agriculture	.511	.553	8.2
Environmental Protection Agency	.104	.136	30.7
Department of Commerce	.029	.030	3.4

NAS ANNOUNCES 1990 OUTSTANDING CONTRIBUTIONS TO SCIENCE AWARD WINNERS

The National Academy of Science (NAS) has announced the winners of it 1990 awards for outstanding contributions to science.

Among the winners are Stanford professor Peter Sturrock, who will receive the Arctowski Medal and $15,000 for increasing our understanding of solar magnetic activity, especially the origin and effects of solar flares. The Memorial Lecture prize of $7500 will go to Klaus Hasselmann, director of the Max Planck Institute for Meteorology, for quantifying ocean waves through satellite observations and for his pioneering work in ocean modelling.

NAS's $15,000 Award for Initiative in Research will be split between MIT professor James Fujimoto and Wayne Knox of AT&T Bell Laboratories for their work in femtosecond quantum electronics and for developing subpicosecond laser applications.

The awards will be presented April 23 at NAS's 127th annual meeting.

****
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****

cc: J.S.
R.S.
OSTP

THE WHITE HOUSE
WASHINGTON

July 20, 90

Memo to: Michael Boskin
From: Allan Bromley
Re: Response of the Semiconductor leaders.

Herewith copies (3) of the letter report that we discussed at our recent meeting. Please see that Richard and John get theirs.

Again my thanks for taking time to meet with me and my senior colleagues. We should do more of this!

Best regards.

JUN 13 1990

J. R. JUNKINS

Ian M. Ross
President

AT&T
Bell Laboratories

Crawfords Corner Road
Holmdel NJ 07733
201 949-3242

June 6, 1990

The Honorable John H. Sununu
Chief of Staff
The White House
1600 Pennsylvania Avenue
Washington, DC 20500

Dear John:

When members of the National Advisory Committee on Semiconductors (NACS) met with you and Dick Darman, Michael Boskin, and Roger Porter on March 20, we agreed to assess the various proposals of the administration affecting capital formation and elaborate on some of our key electronic industry strategies. Attached are three studies; a brief summary of each is given here.

Capital Formation

The Administration has proposed several programs to help improve capital formation in U.S. industry, including lowering the tax rate on capital gains, making the R&D tax cut permanent and increasing incentives for personal savings. Increased investment is important to all American industry, but particularly for the capital intensive semiconductor industry. In the past five years, the Japanese industry has spent $12 billion more on capital equipment and R&D than the U.S. merchant semiconductor industry. This under-investment by the domestic industry, relative to the global competition, has been a key reason for the loss of U.S. market share described in the NACS Annual Report.

NACS has studied the effects of the Administration proposals on the semiconductor industry and finds that, although their effects would be significant, they would not be enough to reverse the projected continuing loss in U.S. semiconductor market share. But, a further change in tax policy, to allow faster depreciation of capital equipment, could have a major effect on capital spending and could substantially narrow the difference in investment rates between the U.S. and Japan. NACS estimates the cost to the Treasury in 1991 of reducing depreciation schedules on semiconductor processing equipment from five to three years is $180 million, and would result in an additional $450 million in new capital spending by U.S. merchant and captive producers (an increase of 11 percent). Detailed estimates of the effect on capital investment and research and development spending expected from each proposal are shown in the summary attached to this letter. The full report will be available in about two months.

Broadband Information Services

The acceleration of Broadband ISDN and fiber to the end user would be an important stimulant to the electronics industry and the nation's information services infrastructure. The U.S. Government can take various actions, which are described in some detail in the attachment, that would be very helpful. For instance, NACS believes that the U.S.G should declare that a

nationwide Broadband information services network is a national goal. Such a goal would still allow the hardware/service vendor to choose the media (copper, coax, fiber) best suited to the application. Also, the U.S.G should use its considerable procurement leverage, and R&D funding, to encourage the widespread utilization of Broadband hardware and services. In addition, the National Research and Education Network (NREN), now addressing supercomputer networking, should develop long-term plans to move towards Broadband ISDN and this R&E network should be expanded into many colleges and high schools with the purpose of raising the quality of college/high school science and mathematics instruction.

Broadband services are an important infrastructural element in the global race to remain competitive. NACS believes that this area is a near ideal place for the government to take a leadership role, and at very little cost. The attached study of critical factors affecting Broadband ISDN and fiber deployment is a statement of the issues, which are complex. We've identified the various bottlenecks that are restraining forward movement in this area. We believe that we have gone about as far as we can without some help regarding the practicality of our suggested actions. Working with someone in your office, on these matters, would be helpful.

Semiconductor Materials and Equipment Industry

The health and robustness of this industry remains crucial to the long-term viability of U.S.-based silicon chip and electronics equipment manufacturing. NACS believes that this industry needs very urgent attention, as the industry trends show further weakening. NACS has now done a more detailed study (the full report will also be available in about two months) of these trends, and we are including a summary of the full 1990 report which is aimed at providing a more thorough analysis of this industry. We have also proposed a set of recommendations that, if implemented, would help to correct the disturbing downward slide of this industry. The NACS report of November 1989 recommended that an additional $100M dollars ($50M from government and $50M matched from industry) be channelled to SEMATECH. These funds were to be spent on various high-priority materials and equipment programs. I am attaching a letter from R. Noyce, CEO of SEMATECH, to John Armstrong of IBM, the technology subgroup chairman for NACS. This letter provides a list of programs that needs extra funds. NACS believes that SEMATECH is an important element of an overall national semiconductor strategy, and that these additional funds are critical to assure that our materials/equipment program underway at SEMATECH continues to have a high likelihood of success.

Since these various recommended actions are both broad-ranging and yet detailed, you may find it desirable to identify someone in your office to work with us. Such an assignment would help to move events along more quickly.

Sincerely,

Ian

Attachments
(I - IV)

Copy to (w/atts.)
Dr. D. Allan Bromley

Blind copy to (w/atts.)
J. Armstrong
R. W. Galvin
J. R. Junkins
T. J. Murrin
C. E. Sporck

NATIONAL ADVISORY COMMITTEE ON SEMICONDUCTORS (NACS) ANALYSIS OF THE IMPACT OF TAX POLICY CHANGES ON CAPITAL FORMATION IN THE U.S. SEMICONDUCTOR INDUSTRY

Background: Since 1984,[1] the Japanese semiconductor industry has outspent the U.S. merchant semiconductor industry--in terms of total spending for investment (buildings and equipment) and R&D--by a total of $12 billion. This capital formation gap translated into a decrease in U.S. world market share from 53 percent in 1980 to 37 percent in 1989. Between 1990 and 1995, the gap in capital formation will widen to over $15 billion, further eroding the U.S. industry's global competitive position in world markets.

Issue Analyzed by the NACS: Is it possible through changes in U.S. tax policy to close or completely eliminate the capital investment gap between the U.S. and Japan's semiconductor industries in order to sustain U.S. technological preeminence and arrest the slide in the U.S. semiconductor industry's global competitive position?

Four Tax Policy Changes Were Analyzed by the NACS:

- Changing the R&D Tax Credit
  - -- The NACS analysis examined the level of semiconductor R&D spending resulting from the current tax credit for R&D spending--which is essentially the same as evaluating the impact of the proposal to make the R&D tax credit permanent--and the required increase in the size of the credit to elevate the industry's rate of R&D spending to the same rate achieved by Japan's semiconductor industry.
  - -- The NACS also evaluated an alternative method for calculating the appropriate credit applicable for all R&D spending.
- Reducing Taxes on Capital Gains
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  - -- Depreciable life for tax purposes for semiconductor equipment is currently five years--this is frequently longer than economic life.
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- Increasing Personal Saving Incentives (Reducing Real Interest Rates)
  - -- The rate of personal savings in the U.S. is lower than among its major competitors, including Japan. The NACS believes that increased savings must be a priority for the U.S.
  - -- To evaluate the benefits of increased savings, the NACS assessed the impact of a reduction in real interest rates of 2 percent (i.e., 200 basis points).

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[1]The first-year data on Japanese spending on both R&D and investment is available.

Table A provides a summary of the impact of the four tax policy changes on the industry's user cost of capital and level of capital formation.[3]

What Will It Take to Close the Capital Formation Gap With the Japanese Industry?:

Figure A indicates for the tax proposals that impact the industry's rate of investment that they can substantially increase the industry's rate of investment spending relative to the rate of Japanese capital spending. This clearly indicates that through appropriate tax policy changes, the capital formation gap with the Japanese semiconductor industry can be significantly reduced. However, just achieving the same rate of investment as the Japanese semiconductor industry by 1995 would still leave a capital formation gap, investment and R&D spending combined, of $9 billion between 1990 and 1995, and fail to arrest the slide in the U.S. global market share.

- With the current capital formation environment unchanged, the U.S. share of total capital investment will fall to 32 percent by 1995--compared to an average of 36 percent between 1984 and 1989. (See Figure B, which shows the relationship between changes in the U.S. share of global investment and the U.S. global market share.) If U.S. tax policies were changed to raise the U.S rate of investment spending relative to sales to the same rate achieved by the Japanese firms, the decline in market share would be slower--only a 2 percent loss over the next five years. If sufficient stimulus to investment were provided to raise U.S. capital spending to the same level as the Japanese capital spending, then the U.S. global market share would remain nearly stable over the next five years.

- With regard to R&D, the analysis suggests that the R&D tax credit, however fashioned, is not a sufficient policy tool, by itself, to completely close the R&D spending gap with the Japanese industry. For example, the rate under the current incremental form of the R&D tax credit would have to be more than double just to lift R&D spending to the same rate as Japan--but would still leave a gap of $3 billion in R&D spending over the next five years. (See Figure C.)

Major Conclusions of the NACS Analysis of the Four Tax Proposals:

- Through tax policy changes, the environment for capital formation in the U.S. semiconductor industry can be substantially improved. At a minimum, it is feasible to raise the rate of investment (relative to industry revenues) to the same rate as the Japanese with some combination of changes in U.S. tax policy. However, even with this improvement, there would still be a shortfall of $6 billion relative to projected total Japanese investment spending. Thus, the NACS concludes that changes in tax policy alone, while beneficial, cannot arrest the decline in the U.S. global market position.

- While changes in U.S. tax policy could substantially benefit capital investment, there would still be a major shortfall in U.S. R&D spending of $3 billion.

- Given the above two conclusions, the NACS concludes that additional stimulus to the U.S. semiconductor industry's rate of capital formation is required from the other NACS recommendations in order to fully address the NACS goals of sustaining U.S. technology preeminence in semiconductors and arresting the slide in the industry's global competitive position. The additional stimulus needed to stabilize the industry's global market share would be equivalent to $4 billion in investment spending over the next five years.

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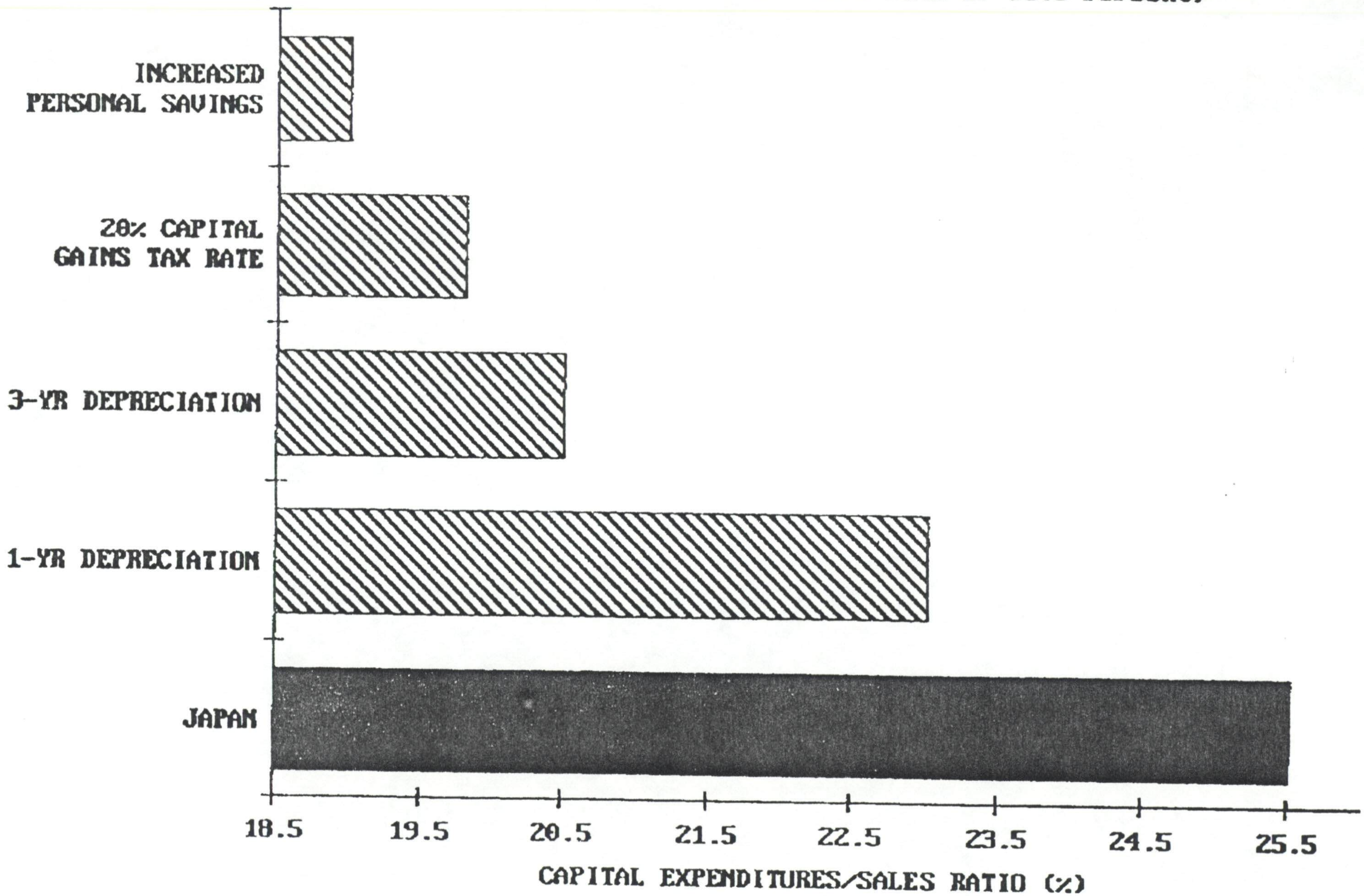
(7) Assumes a 200 basis point decline in real interest rates.

IMPACT OF TAX PROPOSALS ON U.S. MERCHANT SEMICONDUCTOR CAPITAL EXPENDITURES
(Increase Above Current U.S. Rate of 18.5 Percent)



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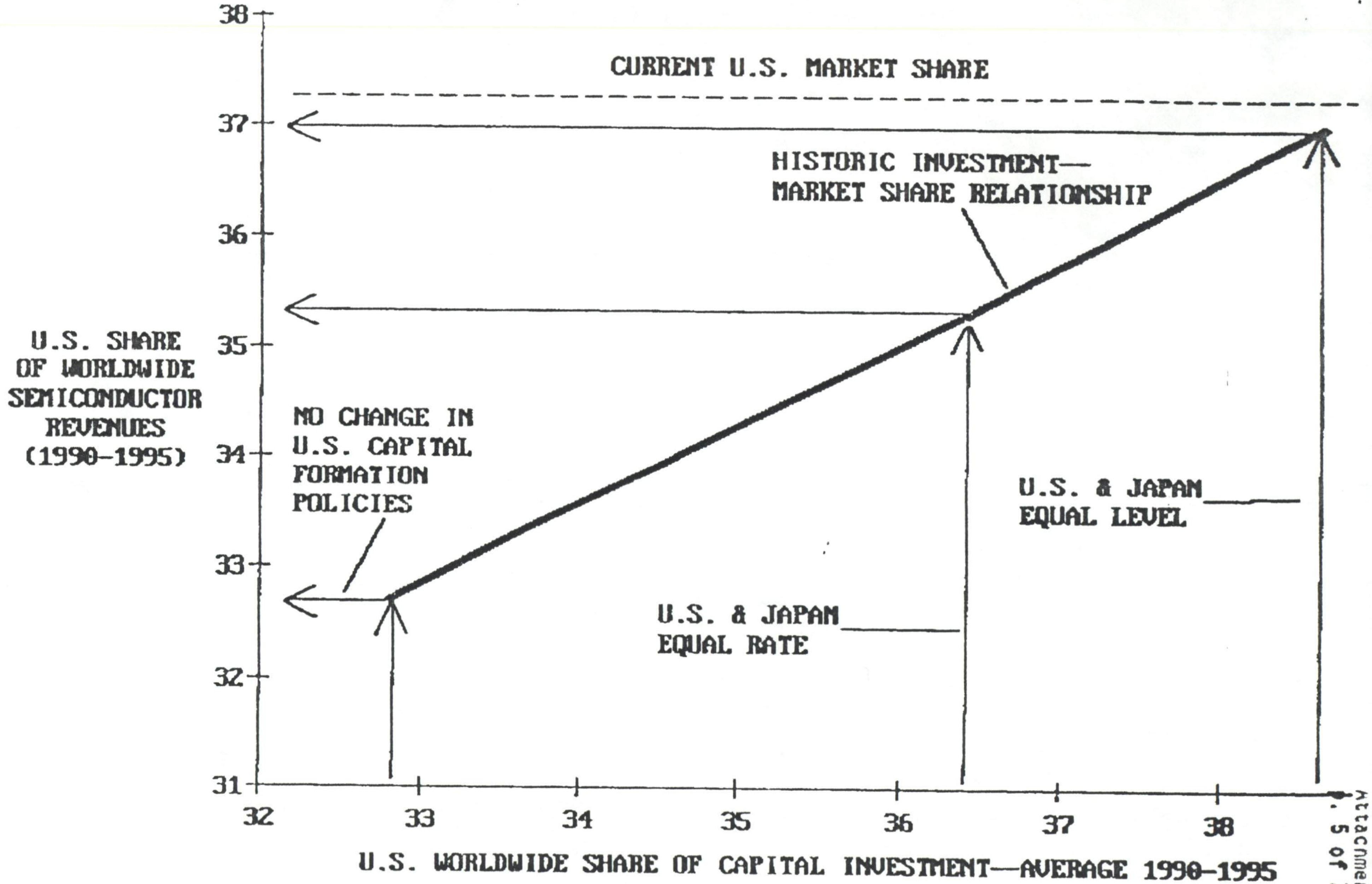

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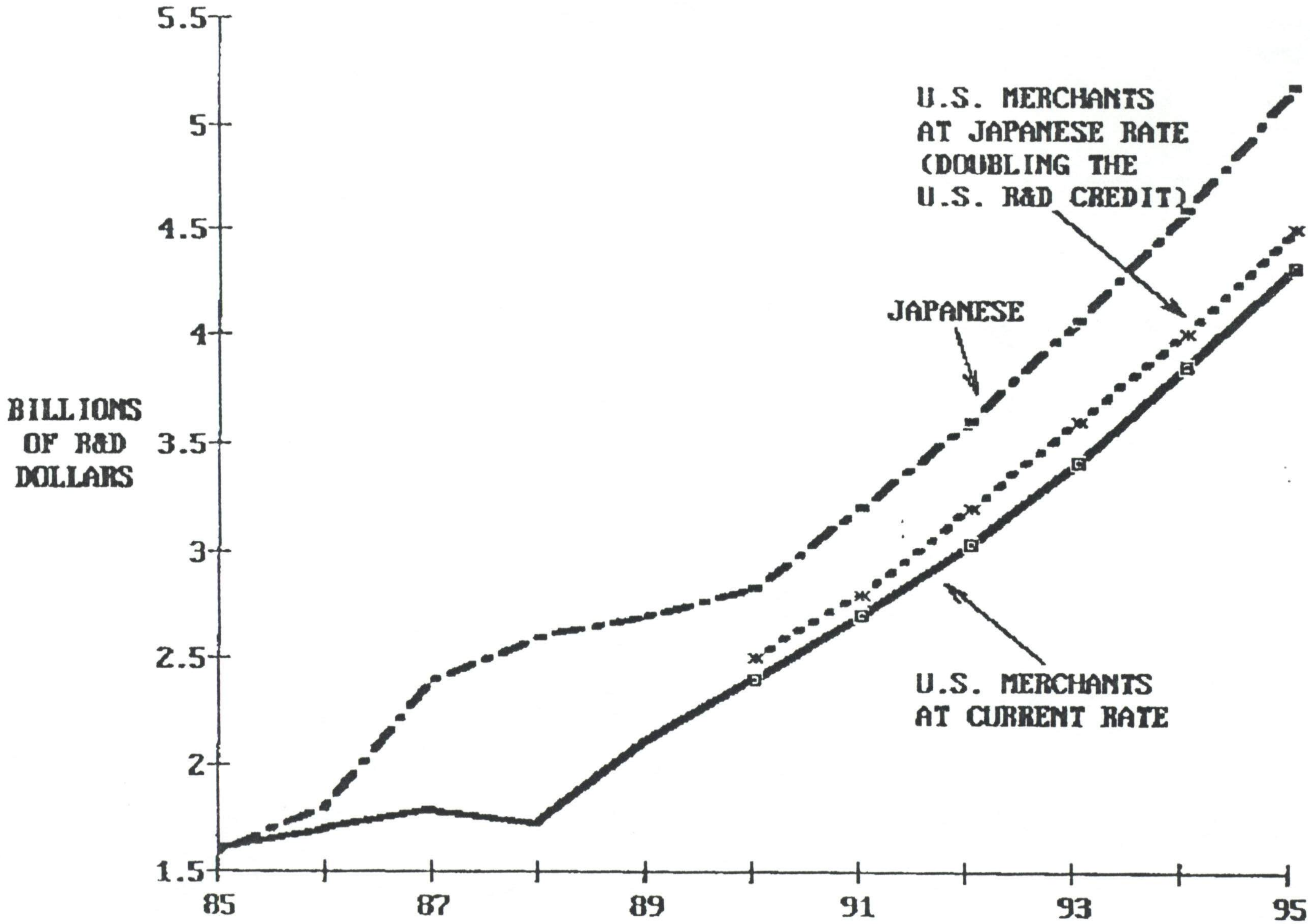

QUICK, FINAN & ASSOCIATES, INC.
SUITE 200
1133 - 21ST STREET, NW
WASHINGTON, DC 20036

TELEPHONE (202) 223-4044
TELECOPIER (202) 296-0085

May 31, 1990

MEMORANDUM FOR: JIM PETERMAN

FROM : BILL FINAN
CHRIS AMUNDSEN

SUBJECT : COST TO TREASURY (TAX REVENUE LOST) OF THREE-YEAR DEPRECIATION OPTION

We prepared the following analysis of the cost to the U.S. Treasury (tax revenue lost) of implementing a three-year depreciation schedule for semiconductor equipment. The analysis compares the estimated current tax payment by both merchants and captive estimated producers to the estimated payments made with the three-year rule in place.

Several points should be noted. First, the estimates provided below represent a change following the first full year of implementation of the revised depreciation policy--in our analysis the first full year would be 1991. The revenue loss can be expected to grow at approximately the same rate as the long-term growth rate of the semiconductor industry--about 13 percent annually. Second, we have made a conservative estimate of the revenue loss in that it assumes that total U.S. semiconductor revenues do not change in response to the accelerated depreciation allowances. As noted in the NACS study, the change in depreciation rules will spur increased U.S. capital investments, which in turn will increase the worldwide market share of U.S.-based firms. This increase in U.S.-based semiconductor revenues would generate additional tax revenues.

(1)	Estimated Tax Payments in 1991 (Base Case)	$690 million
(2)	Estimated Tax Payment in 1991 Under Shortened Depreciation Life Scenario	$510 million
(3)	Cost to Treasury of Three-Year Life	$180 million

We estimate that the three-year depreciation allowance would raise U.S. capital investment by approximately 11 percent. This is equivalent to a $450 million increase in capital investment outlays in 1991 relative to an estimated cost to U.S. Treasury of $180 million. This represents a $2.50 increase in investment for each dollar lost to Treasury.

JUN 13 1990

J. R. JUNKINS

AT&T
Bell Laboratories

Ian M. Ross
President

Crawfords Corner Road
Holmdel NJ 07733
201 949-3242

June 6. 1990

The Honorable John H. Sununu
Chief of Staff
The White House
1600 Pennsylvania Avenue
Washington, DC 20500

Dear John:

When members of the National Advisory Committee on Semiconductors (NACS) met with you and Dick Darman, Michael Boskin, and Roger Porter on March 20, we agreed to assess the various proposals of the administration affecting capital formation and elaborate on some of our key electronic industry strategies. Attached are three studies; a brief summary of each is given here.

Capital Formation

The Administration has proposed several programs to help improve capital formation in U.S. industry, including lowering the tax rate on capital gains, making the R&D tax cut permanent and increasing incentives for personal savings. Increased investment is important to all American industry, but particularly for the capital intensive semiconductor industry. In the past five years, the Japanese industry has spent $12 billion more on capital equipment and R&D than the U.S. merchant semiconductor industry. This under-investment by the domestic industry, relative to the global competition, has been a key reason for the loss of U.S. market share described in the NACS Annual Report.

NACS has studied the effects of the Administration proposals on the semiconductor industry and finds that, although their effects would be significant, they would not be enough to reverse the projected continuing loss in U.S. semiconductor market share. But, a further change in tax policy, to allow faster depreciation of capital equipment, could have a major effect on capital spending and could substantially narrow the difference in investment rates between the U.S. and Japan. NACS estimates the cost to the Treasury in 1991 of reducing depreciation schedules on semiconductor processing equipment from five to three years is $180 million, and would result in an additional $450 million in new capital spending by U.S. merchant and captive producers (an increase of 11 percent). Detailed estimates of the effect on capital investment and research and development spending expected from each proposal are shown in the summary attached to this letter. The full report will be available in about two months.

Broadband Information Services

The acceleration of Broadband ISDN and fiber to the end user would be an important stimulant to the electronics industry and the nation's information services infrastructure. The U.S. Government can take various actions, which are described in some detail in the attachment, that would be very helpful. For instance, NACS believes that the U.S.G should declare that a

nationwide Broadband information services network is a national goal. Such a goal would still allow the hardware/service vendor to choose the media (copper, coax, fiber) best suited to the application. Also, the U.S.G should use its considerable procurement leverage, and R&D funding, to encourage the widespread utilization of Broadband hardware and services. In addition, the National Research and Education Network (NREN), now addressing supercomputer networking, should develop long-term plans to move towards Broadband ISDN and this R&E network should be expanded into many colleges and high schools with the purpose of raising the quality of college/high school science and mathematics instruction.

Broadband services are an important infrastructural element in the global race to remain competitive. NACS believes that this area is a near ideal place for the government to take a leadership role, and at very little cost. The attached study of critical factors affecting Broadband ISDN and fiber deployment is a statement of the issues, which are complex. We've identified the various bottlenecks that are restraining forward movement in this area. We believe that we have gone about as far as we can without some help regarding the practicality of our suggested actions. Working with someone in your office, on these matters, would be helpful.

Semiconductor Materials and Equipment Industry

The health and robustness of this industry remains crucial to the long-term viability of U.S.-based silicon chip and electronics equipment manufacturing. NACS believes that this industry needs very urgent attention, as the industry trends show further weakening. NACS has now done a more detailed study (the full report will also be available in about two months) of these trends, and we are including a summary of the full 1990 report which is aimed at providing a more thorough analysis of this industry. We have also proposed a set of recommendations that, if implemented, would help to correct the disturbing downward slide of this industry. The NACS report of November 1989 recommended that an additional $100M dollars ($50M from government and $50M matched from industry) be channelled to SEMATECH. These funds were to be spent on various high-priority materials and equipment programs. I am attaching a letter from R. Noyce, CEO of SEMATECH, to John Armstrong of IBM, the technology subgroup chairman for NACS. This letter provides a list of programs that needs extra funds. NACS believes that SEMATECH is an important element of an overall national semiconductor strategy, and that these additional funds are critical to assure that our materials/equipment program underway at SEMATECH continues to have a high likelihood of success.

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NATIONAL ADVISORY COMMITTEE ON SEMICONDUCTORS (NACS) ANALYSIS OF THE IMPACT OF TAX POLICY CHANGES ON CAPITAL FORMATION IN THE U.S. SEMICONDUCTOR INDUSTRY

<u>Background:</u> Since 1984,[1] the Japanese semiconductor industry has outspent the U.S. merchant semiconductor industry--in terms of total spending for investment (buildings and equipment) and R&D--by a total of $12 billion. This capital formation gap translated into a decrease in U.S. world market share from 53 percent in 1980 to 37 percent in 1989. Between 1990 and 1995, the gap in capital formation will widen to over $15 billion, further eroding the U.S. industry's global competitive position in world markets.

<u>Issue Analyzed by the NACS:</u> Is it possible through changes in U.S. tax policy to close or completely eliminate the capital investment gap between the U.S. and Japan's semiconductor industries in order to sustain U.S. technological preeminence and arrest the slide in the U.S. semiconductor industry's global competitive position?

<u>Four Tax Policy Changes Were Analyzed by the NACS:</u>

- Changing the R&D Tax Credit
  - -- The NACS analysis examined the level of semiconductor R&D spending resulting from the current tax credit for R&D spending--which is essentially the same as evaluating the impact of the proposal to make the R&D tax credit permanent--and the required increase in the size of the credit to elevate the industry's rate of R&D spending to the same rate achieved by Japan's semiconductor industry.
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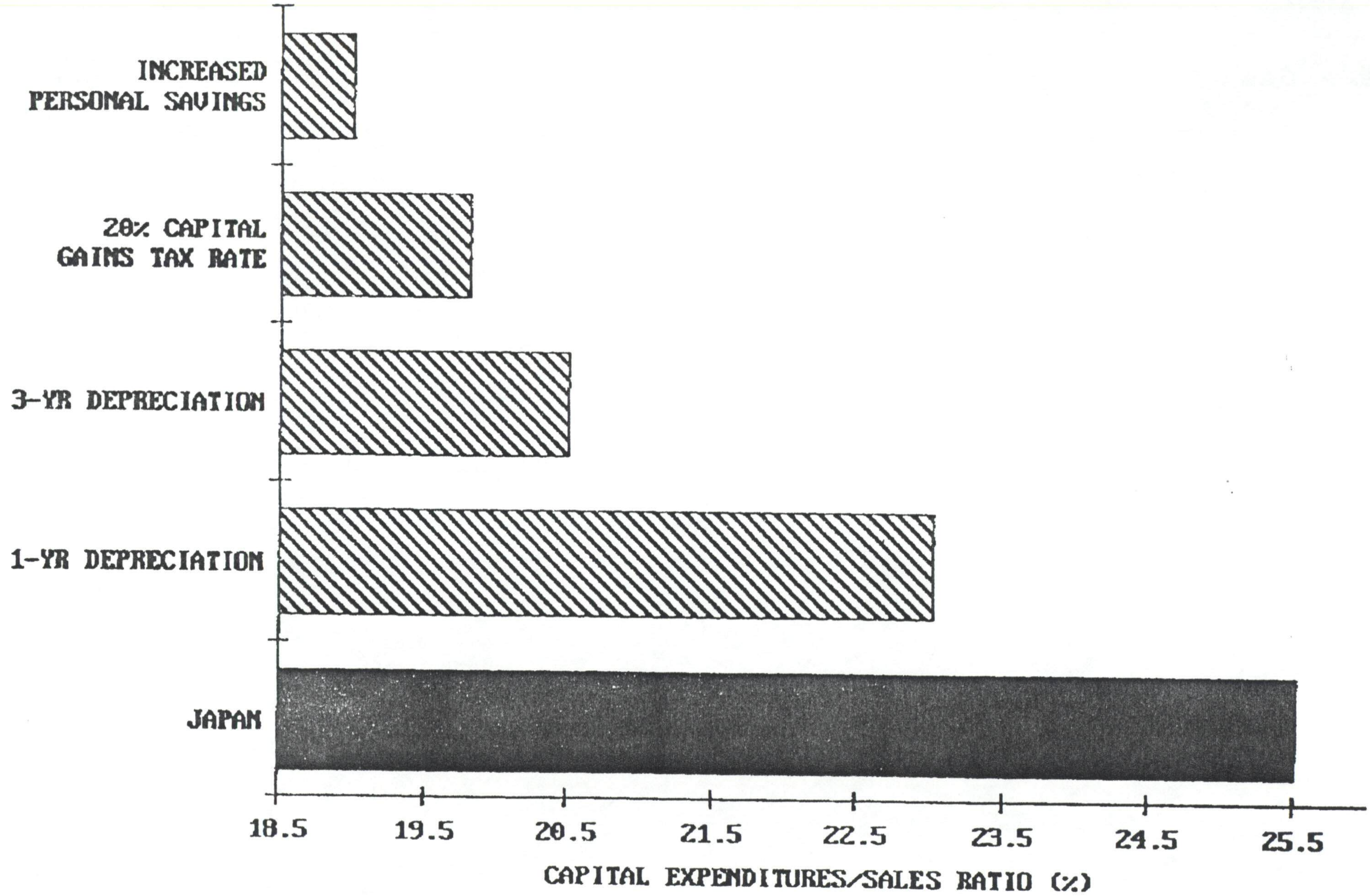

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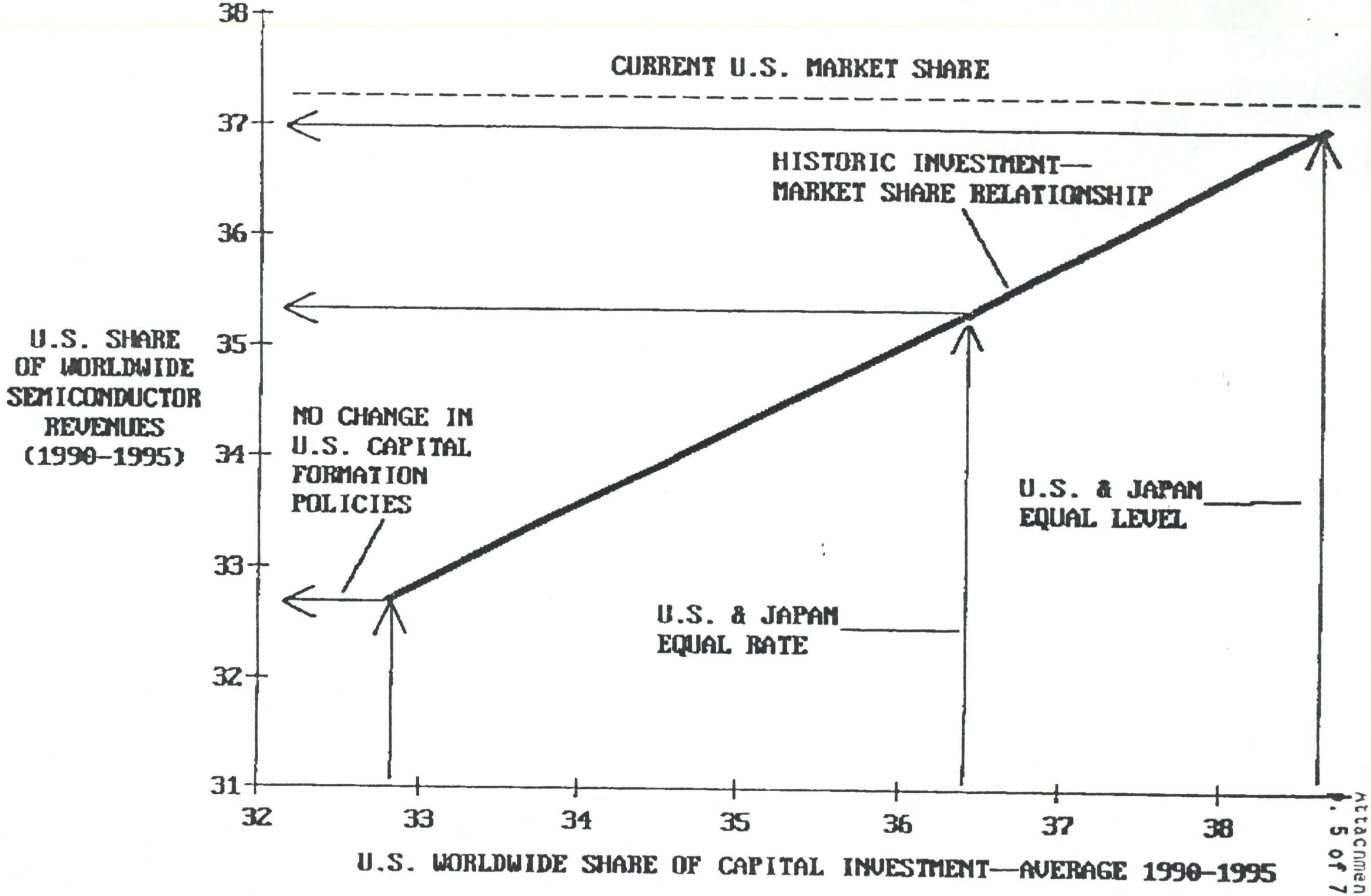

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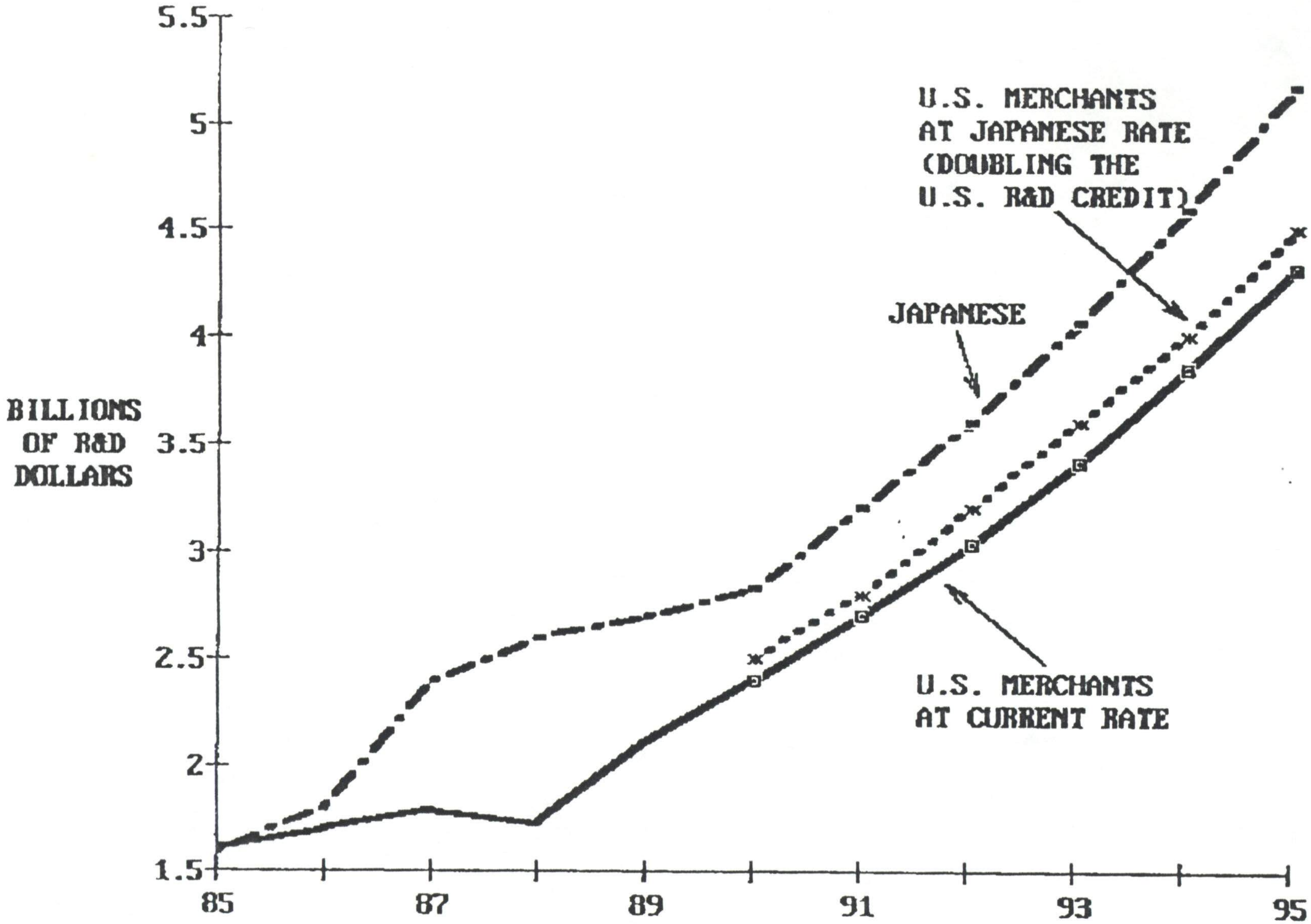

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TELECOPIER (202) 296-0085

May 31, 1990

MEMORANDUM FOR: JIM PETERMAN

FROM : BILL FINAN
CHRIS AMUNDSEN

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JUN 13 1990

J. R. JUNKINS

AT&T
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Ian M. Ross
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June 6. 1990

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OCT 18 '90 08:44 AM *TI INDUSTRY AFFAIRS P.03

NATIONAL ADVISORY COMMITTEE ON SEMICONDUCTORS (NACS) ANALYSIS OF THE IMPACT OF TAX POLICY CHANGES ON CAPITAL FORMATION IN THE U.S. SEMICONDUCTOR INDUSTRY

<u>Background:</u> Since 1984,[1] the Japanese semiconductor industry has outspent the U.S. merchant semiconductor industry--in terms of total spending for investment (buildings and equipment) and R&D--by a total of $12 billion. This capital formation gap translated into a decrease in U.S. world market share from 53 percent in 1980 to 37 percent in 1989. Between 1990 and 1995, the gap in capital formation will widen to over $15 billion, further eroding the U.S. industry's global competitive position in world markets.

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<u>Four Tax Policy Changes Were Analyzed by the NACS:</u>

- Changing the R&D Tax Credit
  - The NACS analysis examined the level of semiconductor R&D spending resulting from the current tax credit for R&D spending--which is essentially the same as evaluating the impact of the proposal to make the R&D tax credit permanent--and the required increase in the size of the credit to elevate the industry's rate of R&D spending to the same rate achieved by Japan's semiconductor industry.
  - The NACS also evaluated an alternative method for calculating the appropriate credit applicable for all R&D spending.
- Reducing Taxes on Capital Gains
  - The NACS evaluated the impact of the Administration's proposal on capital gains.
- Aligning Depreciation Rules for Semiconductor Equipment to Economic Life
  - Depreciable life for tax purposes for semiconductor equipment is currently five years--this is frequently longer than economic life.
  - The NACS evaluated: (1) allowing a three-year life for tax depreciation of equipment--a period closer to the realistic life for many types of equipment; and (2) allowing a one-year life for tax purposes--a period shorter than realistic life but used to illustrate the responsiveness of investment to this policy change.
- Increasing Personal Saving Incentives (Reducing Real Interest Rates)
  - The rate of personal savings in the U.S. is lower than among its major competitors, including Japan. The NACS believes that increased savings must be a priority for the U.S.
  - To evaluate the benefits of increased savings, the NACS assessed the impact of a reduction in real interest rates of 2 percent (i.e., 200 basis points).

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[1]The first-year data on Japanese spending on both R&D and investment is available.

Table A provides a summary of the impact of the four tax policy changes on the industry's user cost of capital and level of capital formation.[3]

What Will It Take to Close the Capital Formation Gap With the Japanese Industry?:

Figure A indicates for the tax proposals that impact the industry's rate of investment that they can substantially increase the industry's rate of investment spending relative to the rate of Japanese capital spending. This clearly indicates that through appropriate tax policy changes, the capital formation gap with the Japanese semiconductor industry can be significantly reduced. However, just achieving the same rate of investment as the Japanese semiconductor industry by 1995 would still leave a capital formation gap, investment and R&D spending combined, of $9 billion between 1990 and 1995, and fail to arrest the slide in the U.S. global market share.

- With the current capital formation environment unchanged, the U.S. share of total capital investment will fall to 32 percent by 1995--compared to an average of 36 percent between 1984 and 1989. (See Figure B, which shows the relationship between changes in the U.S. share of global investment and the U.S. global market share.) If U.S. tax policies were changed to raise the U.S rate of investment spending relative to sales to the same rate achieved by the Japanese firms, the decline in market share would be slower--only a 2 percent loss over the next five years. If sufficient stimulus to investment were provided to raise U.S. capital spending to the same level as the Japanese capital spending, then the U.S. global market share would remain nearly stable over the next five years.

- With regard to R&D, the analysis suggests that the R&D tax credit, however fashioned, is not a sufficient policy tool, by itself, to completely close the R&D spending gap with the Japanese industry. For example, the rate under the current incremental form of the R&D tax credit would have to be more than double just to lift R&D spending to the same rate as Japan--but would still leave a gap of $3 billion in R&D spending over the next five years. (See Figure C.)

Major Conclusions of the NACS Analysis of the Four Tax Proposals:

- Through tax policy changes, the environment for capital formation in the U.S. semiconductor industry can be substantially improved. At a minimum, it is feasible to raise the rate of investment (relative to industry revenues) to the same rate as the Japanese with some combination of changes in U.S. tax policy. However, even with this improvement, there would still be a shortfall of $6 billion relative to projected total Japanese investment spending. Thus, the NACS concludes that changes in tax policy alone, while beneficial, cannot arrest the decline in the U.S. global market position.

- While changes in U.S. tax policy could substantially benefit capital investment, there would still be a major shortfall in U.S. R&D spending of $3 billion.

- Given the above two conclusions, the NACS concludes that additional stimulus to the U.S. semiconductor industry's rate of capital formation is required from the other NACS recommendations in order to fully address the NACS goals of sustaining U.S. technology preeminence in semiconductors and arresting the slide in the industry's global competitive position. The additional stimulus needed to stabilize the industry's global market share would be equivalent to $4 billion in investment spending over the next five years.

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[3]The results shown in Table A do not include accounting for any changes in the overall macroeconomic climate that the change might create; nor do they include in the potential cumulative impact of higher industry output due to the higher investment levels

TABLE A

Summary of Impact of Capital Formation Proposals(1,2)

Proposal	Percent Change		
	Cost of Capital	Capital Investment	R&D Spending(3)
A. R&D Tax Credit			
Continue Current(4)	-2 to -7	not estimated	+1 to +2
Increase Rate(5)	-44	not estimated	+5
Change Base(6)	-5	not estimated	+5
B. Capital Gains Tax Cut	not estimated	+7	not estimated
C. Improving Depreciation Rules			
3-Year	-16	+11	not estimated
1-Year	-29	+26	not estimated
D. Personal Savings Incentives(7)	-15	+3	not estimated

Notes:

(1) Appendix 1 to the complete NACS report on Capital Formation has a detailed discussion of each proposal.

(2) Appendix 2 to the complete NACS report on Capital Formation discusses the "Tobin Q Theory", which was used to estimate the impact of each proposal on investment.

(3) Percentage increase relative to estimated 1990 level of merchant semiconductor R&D spending.

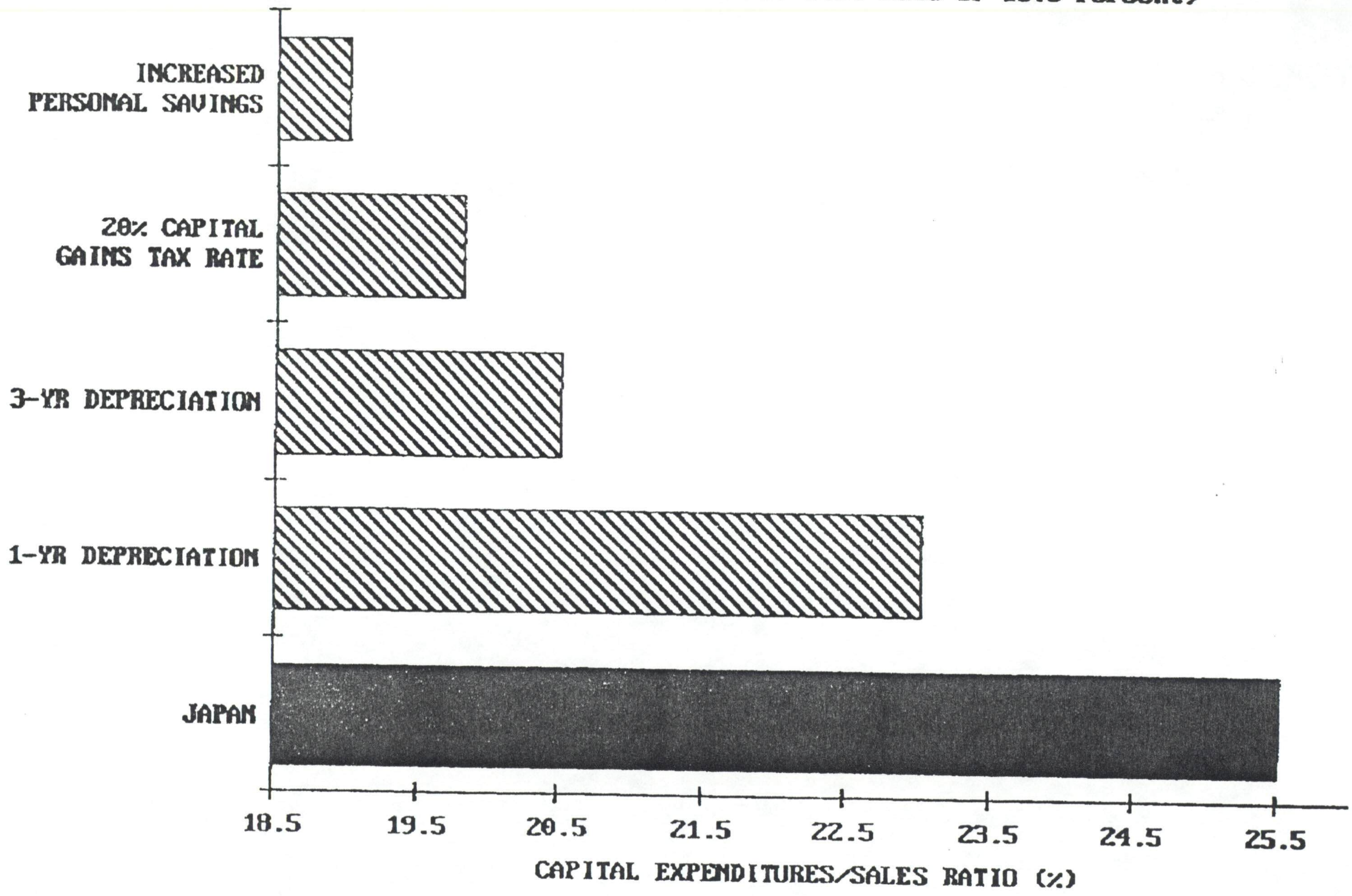
(4) Assume a permanent tax credit. Changes in the cost of capital apply only to incremental R&D spending which is eligible for the tax credit.

(5) Credit increased to 50 percent--a rate sufficient to achieve parity with the 1988 Japanese rate of R&D spending relative to sales. Changes in the cost of capital apply only to incremental R&D spending which is eligible for the tax credit.

(6) Assumes a 3 percent credit applies to the total base of R&D spending--a rate sufficient to achieve parity with the 1988 Japanese rate of R&D spending relative to sales. Changes in the cost of capital apply to all R&D spending.

(7) Assumes a 200 basis point decline in real interest rates.

IMPACT OF TAX PROPOSALS ON U.S. MERCHANT SEMICONDUCTOR CAPITAL EXPENDITURES
(Increase Above Current U.S. Rate of 18.5 Percent)



INCREASING THE U.S. SHARE OF WORLDWIDE INVESTMENT IS NECESSARY TO MAINTAIN U.S. WORLDWIDE MARKET SHARE AT ITS CURRENT LEVEL

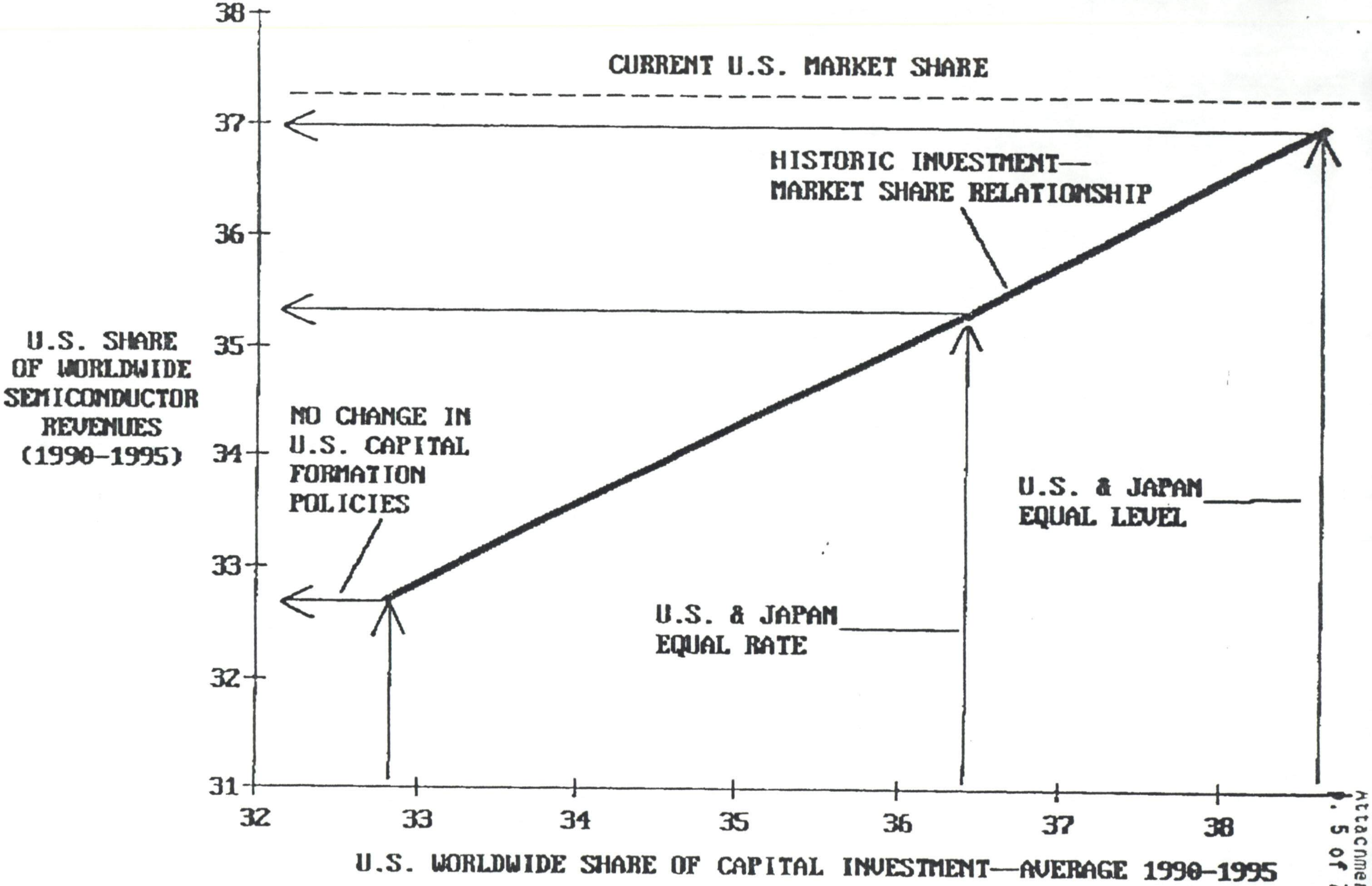
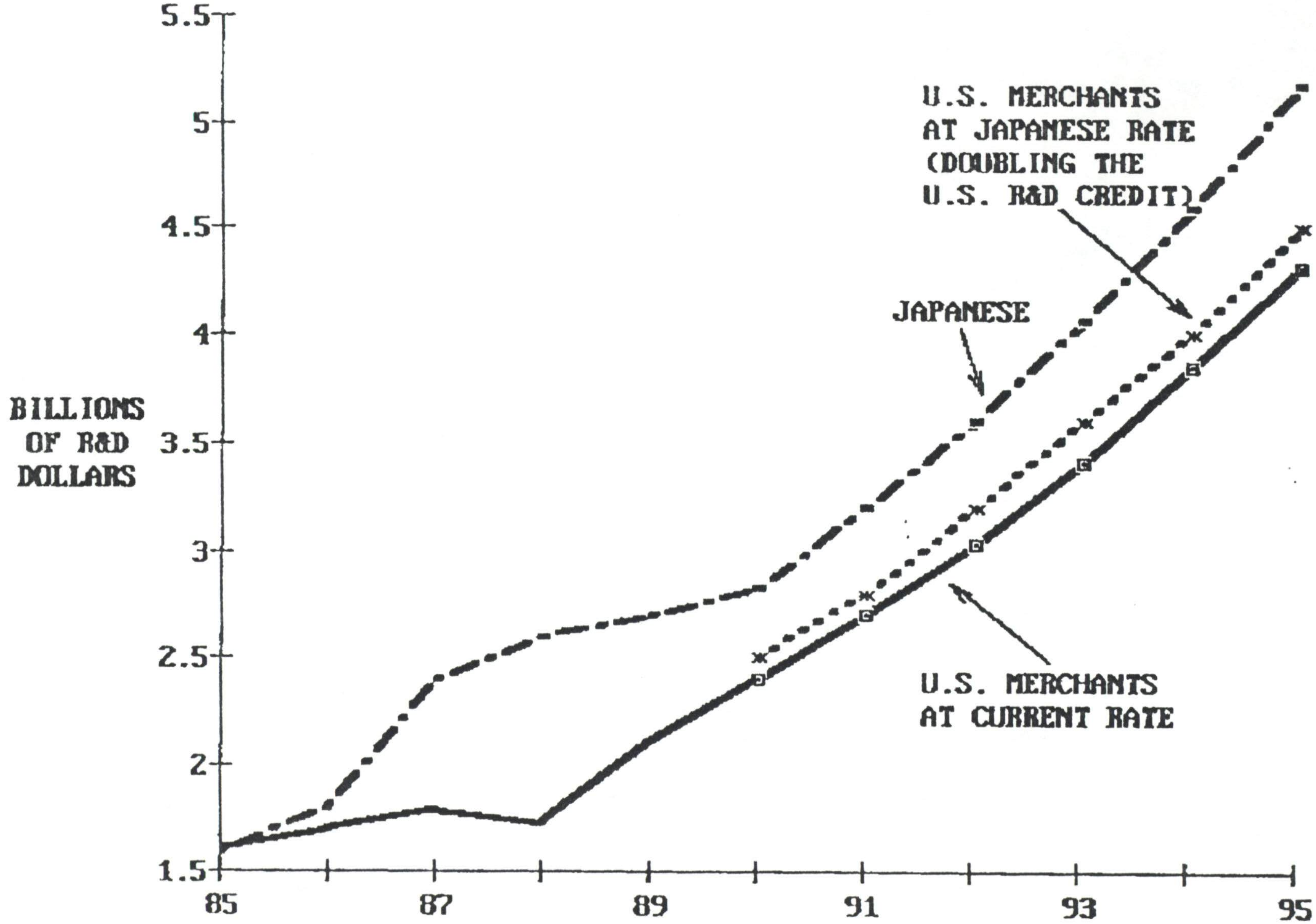


FIGURE C

AN EFFECTIVE R&D CREDIT CAN HELP CLOSE THE R&D SPENDING GAP WITH JAPAN



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May 31, 1990

MEMORANDUM FOR: JIM PETERMAN

FROM : BILL FINAN
CHRIS AMUNDSEN

SUBJECT : COST TO TREASURY (TAX REVENUE LOST) OF THREE-YEAR DEPRECIATION OPTION

We prepared the following analysis of the cost to the U.S. Treasury (tax revenue lost) of implementing a three-year depreciation schedule for semiconductor equipment. The analysis compares the estimated current tax payment by both merchants and captive estimated producers to the estimated payments made with the three-year rule in place.

Several points should be noted. First, the estimates provided below represent a change following the first full year of implementation of the revised depreciation policy--in our analysis the first full year would be 1991. The revenue loss can be expected to grow at approximately the same rate as the long-term growth rate of the semiconductor industry--about 13 percent annually. Second, we have made a conservative estimate of the revenue loss in that it assumes that total U.S. semiconductor revenues do not change in response to the accelerated depreciation allowances. As noted in the NACS study, the change in depreciation rules will spur increased U.S. capital investments, which in turn will increase the worldwide market share of U.S.-based firms. This increase in U.S.-based semiconductor revenues would generate additional tax revenues.

(1)	Estimated Tax Payments in 1991 (Base Case)	$690 million
(2)	Estimated Tax Payment in 1991 Under Shortened Depreciation Life Scenario	<u>$510 million</u>
(3)	Cost to Treasury of Three-Year Life	$180 million

We estimate that the three-year depreciation allowance would raise U.S. capital investment by approximately 11 percent. This is equivalent to a $450 million increase in capital investment outlays in 1991 relative to an estimated cost to U.S. Treasury of $180 million. This represents a $2.50 increase in investment for each dollar lost to Treasury.