

BIBLIOGRAPHY

Publications by the National Science and Technology Council

Interagency Working Group on Nano Science, Engineering, and Technology. *Nanotechnology Research Directions*. September 1999. Available at: <http://nano.gov/> and published by Kluwer Academic Publishers, 2000. This publication incorporates a vision for how the nanotechnology community — Federal agencies, industries, universities, and professional societies — can coordinate efforts more effectively to develop a wide range of revolutionary commercial applications. It identifies challenges and opportunities in the nanotechnology field and begins to make recommendations on how to develop a balanced infrastructure for nanotechnology R&D, advance critical research areas, and nurture the scientific and technical workforce of the next century.

Interagency Working Group on Nano Science, Engineering, and Technology. *Nanostructure Science and Technology: A Worldwide Study*. August 1999. Available at: <http://nano.gov/> and published by Kluwer Academic Publishers, 2000. This report reviews the status of R&D in nanoparticles, nanostructured materials, and nanodevices, including innovative approaches to synthesis and characterization. The report highlights applications in dispersions, high-surface-area materials, electronic and magnetic devices, nanostructured materials, and biological systems. It includes a comparative review of research programs around the world — the United States, Japan, Western Europe, and other countries — to provide a global picture of the field.

Interagency Working Group on Nano Science, Engineering, and Technology. *Nanotechnology: Shaping the World Atom by Atom*. December 1999. Available at: <http://nano.gov/>. This brochure sets the stage for increasing the public's understanding of what nanotechnology is, how it came to be, and its potential impact on society.

Interagency Working Group on Nano Science, Engineering, and Technology. *National Nanotechnology Initiative – Leading to the Next Industrial Revolution*. February 2000. Available at: <http://nano.gov/>. This report supplements the President's FY 2001 budget and highlights the nanotechnology funding mechanisms developed for this new initiative and the funding allocations for each participating Federal agency.

Subcommittee on Nanoscale Science, Engineering, and Technology. *National Nanotechnology Initiative: The Initiative and its Implementation Plan*. July 2000. Available at: <http://nano.gov/>. This report includes the description of the initiative and its implementation plan for eight U.S. Government departments and agencies.

Other Publications

Bimber, B., and Guston, D., eds., *Technology Assessment: The End of OTA*, special issue of *Technology Forecasting and Social Change*, Vol. 54, No. 2 and 3, 1997

Christensen, Clayton M. *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. New York: Harperbusiness, 2000.

- Freitas, L. *Nanomedicine*. Bioscience, 1999.
- Joy, Bill. "Why the Future Doesn't Need Us." *Wired*, April 8, 2000. http://www.wired.com/wired/archive/8.04/joy_pr.html/.
- Kennedy, Paul. *The Rise and Fall of the Great Powers, Economic Change and Military Conflict from 1500 to 2000*. New York: Random House, 1987.
- National Human Genome Research Institute, *Ethical, Legal, and Social Implications of Human Genetics Research of the National Institutes of Health*. Available at: <http://www.nhgri.nih.gov/ELSI>, October 2000.
- National Coordination Office for Information Technology, *Ethical, Legal, and Societal Implications of Information Technology Research and Development*. Available at: <http://www.itrd.gov>, October 1999.
- Smith, A., *The Wealth of Nations: An Inquiry into the Nature and Causes*, Random House, New York, 1994.
- RAND Corporation. *The Potential of Nanotechnology for Molecular Manufacturing*. 1995.
- Winner, Langdon, ed., *Democracy in a Technological Society, in Philosophy and Technology*, Vol. 9, Kluwer Academic Publishers, Dordrecht, The Netherlands, 1992.

APPENDICES

Appendix A. List of Participants and Contributors

Government and National Laboratories

William S. Bainbridge
Science Advisor
National Science Foundation
Directorate for Social, Behavioral &
Economic Sciences
4201 Wilson Blvd., Suite 525
Arlington, VA 22230

Michael E. Davey
Analyst in Science and Technology
Congressional Research Service (CRS)
CRS-STM-LM413
Library of Congress
Washington, D.C.20540-7490

Joseph Bordogna
Deputy Director
National Science Foundation
4201 Wilson Blvd., Suite 1205 N.
Arlington, VA 22230

Mildred S. Dresselhaus
Director, Office of Science
Bldg. FORS, Rm. 7B-058
Department of Energy
1000 Independence Avenue, S.W.
Washington, DC 20585

Rita Colwell
Director
National Science Foundation
4201 Wilson Blvd., Suite 1205 N.
Arlington, VA 22230

Murray S. Hirschbein
NASA Headquarters
Building: HQ, Room: 6D70
Washington DC 20546-0001

Joanne D. Culbertson
Senior Advisor for Planning and
Evaluation
National Science Foundation
Directorate for Engineering
4201 Wilson Blvd., Suite 505 N
Arlington, VA 22230

Tom Kalil
Special Assistant to the President
National Economic Council, White
House
230 OEOB
Washington, D.C. 20502

Michael Daum
National Economic Council
Executive Office of the President

Richard D. Kelley
U.S. Department of Energy
Materials Sciences Division
SC-13, Rm. F-421
Building: GTN
Washington, DC 20545

Richard D. Klausner
Director
National Cancer Institute
NIH, Building 31, Room 11A-48
31 Center Drive
Bethesda, MD 20892-2590

Annalynn Lacombe
DOT Volpe National Transportation
System Center
55 Broadway, Kendall Square
Cambridge, MA 02142

Elbert L. Marsh
Deputy Assistant Director
National Science Foundation
Directorate for Engineering
4201 Wilson Blvd., Suite 505 N
Arlington, VA 22230

Louis A. Martin-Vega
Assistant Director (Acting)
National Science Foundation
Directorate for Engineering
4201 Wilson Blvd., Rm. 505 N
Arlington, VA 22230

James S. Murday,
Superintendent
Chemistry Division
Naval Research Laboratory
Code 6100
Washington, D.C. 20375-5342

S. Tom Picraux
Director, Physical & Chemical Sciences
Center
Sandia National Labs
P.O. Box 5800
Albuquerque, NM 87185-1427

Gernot S. Pomrenke
Mathematics and Space Sciences
Directorate
Air Force Office of Scientific Research
Ballston Common Towers II
801 N. Randolph Street, Rm. 732
Arlington, VA 22203

M.C. Roco
Senior Advisor for Nanotechnology
National Science Foundation
Division of Chemical and Transport
Systems
4201 Wilson Blvd., Suite 525
Arlington, VA 22230

Miron L. Straf
National Science Foundation
Directorate for Social, Behavioral &
Economic Sciences
4201 Wilson Blvd., Suite 525
Arlington, VA 22230

Samuel Venneri
Chief Technologist
National Aeronautics and Space
Administration
Headquarters Building, Rm. 9S13
Washington DC 20546-0001

Gerold Yonas
Principal Scientist
Sandia National Laboratory
P. O. Box 5800
Albuquerque, NM 87185-0839

Academic Contributors

April S. Brown
Georgia Institute of Technology
College of Engineering

John Carroll
MIT Sloan School
50 Memorial Dr.
Cambridge, MA 02142

Michael M. Crow
Executive Vice Provost
Columbia University
305 Low Library MC 4312
535 W. 116th St.
New York, NY 10027

Henry Etzkowitz
Science Policy Institute
State University of New York, Purchase
735 Anderson Hill Rd.
Purchase, NY 10577

Irwin Feller
Institute for Policy Research and
Evaluation
Department of Economics
N250 Burrowes Building
Pennsylvania State University
University Park, PA 16802

Stephen J. Fonash
Nanofabrication Facility
Penn State University

M. Gregory Forest
Prof. of Mathematics
The University of North Carolina at
Chapel Hill
CB# 3100, South Building
Chapel Hill, NC 27599-3100

Felice Frankel
Project Director, “Envisioning Science”
MIT
77 Massachusetts Avenue
4-405 , Lab: 13-2050
Cambridge, MA 02139

Hans Glimell
Technology and Science Studies
Göteborg University
Box 700, SE 405 30
Göteborg, Sweden

Evelyn Hu
Center for Quantized Electronic
Structures
Science & Technology Center
University of California
Santa Barbara, CA 93106

Kristina M Johnson
Dean, School of Engineering
Duke University
305 Teer Engineering Library
Box 90271
Durham, NC 27708

Robert Langer
MIT
E25-342
77 Massachusetts Avenue
Cambridge, MA 02139

David A Lavan
MIT
E25-342
77 Massachusetts Avenue
Cambridge, MA 02139

Lester B. Lave
James Higgins Professor of Economics
and Finance,
Professor of Urban and Public Affairs,
Professor of Engineering and Public
Policy
Carnegie Mellon University
5000 Forbes Avenue
Pittsburgh, PA 15213

J. Christopher Love
Department of Chemistry and Chemical
Biology
Harvard University
12 Oxford St. – Box #362
Cambridge, MA 02138

James Merz
Vice President for Graduate Studies and
Research
University of Notre Dame
208 Hurley Hall
Notre Dame, IN 46556-5641

Daniel Sarewitz
Center for Science, Policy, and
Outcomes
Columbia University
209 Pennsylvania Ave., SE
Washington, DC 2000

Richard Smalley
Chemistry Department
Smalley Research MS100
Rice University
P.O. Box 1892
Houston, TX 77251-1892

Samuel I. Stupp
Northwestern University
Materials and Life Sciences Building
2225 N. Campus Drive
Evanston, IL 60208

Mark Suchman
The Health Policy Scholars Program
Yale University
89 Trumbull St.
New Haven, CT 06520

Edward Tenner
Department of Geosciences
Princeton University
Princeton, NJ 08544

Paul B. Thompson
Distinguished Professor
Department of Philosophy
1360 LAEB
Purdue University
West Lafayette, IN 47907-1360

Viola Vogel
Director, Center for Nanotechnology
Dept. of Bioengineering
University of Washington
231 Wilcox Hall, Box 352125
Seattle, WA 98195

Vivian Weil
Center for the Study of Ethics in the
Professions
Room 102A, Stuart Building
Illinois Institute of Technology
3300 South Federal Street
Chicago, IL 60616-3793

George Whitesides
Harvard University
Department of Chemistry
12 Oxford St., Mallinckrodt 230
Cambridge, MA 02138

Robert Doering
Texas Instruments
P.O. Box 650311
MS 3730
Dallas, TX 75265

Frank A Wolak
Department of Economics
Stanford University
Stanford, CA 94305-6072

Stephen W. Drew
Merck & Co. (retired)
P.O. Box 2000
Rahway, NJ 07065

Private Sector Contributors

John Armstrong
IBM (retired)
PMB 161,
6 University Dr., Suite 206
Amherst, MA 01002-3820.

Juan M. Garces
Dow Corporate R&D
Building 1776
Midland, MI 48674

John Seely Brown
Xerox Palo Alto Research Center
3333 Coyote Hill Road
Palo Alto, CA 94304

Newt Gingrich
American Enterprise Institute (for Public
Policy Research)
atten: Anne Beighey, Project Director
1150 17th Street, N.W.
Washington, D.C. 20036

James Canton
President, Institute for Global Futures
2084 Union St.
San Francisco CA

Michael J. Heller
Nanogen
10398 Pacific Center Ct.
San Diego, CA 92121

Praveen Chaudhari
IBM Watson Research Center

Phil Kuekes
Hewlett Packard Laboratories
3500 Deer Creek Rd.
MS 26U-12
Palo Alto, CA 94304-1126

Marty C. Cornell
Dow Automotive R&D
Dow Chemical
Auburn Hills, MI 48326

Martin Stephan Meyer
PO Box 3283
Brighton BN1 4TD
East Sussex, United Kingdom

Bonnie A. Nardi
Agilent Laboratories
3500 Deer Creek Rd., MS 24M-A
Palo Alto, CA 94304

William M. Tolles, Consultant
(Naval Research Laboratory, Retired)
8801 Edward Gibbs Place
Alexandria, VA 22309

Richard H. Smith, II
4455 Connecticut Avenue
NW Washington, DC 20008

Stan Williams
Principal Laboratory Scientist
Hewlett Packard Laboratories
3500 Deer Creek Rd.
MS 26U-12
Palo Alto, CA 94304-1126

Tom N. Theis
Director, Physical Sciences
IBM Research,
T.J. Watson Research Center

Appendix B. Selected Endorsements of NNI

(see also: <http://nano.gov>)

Below are NNI endorsements made in 1999 and 2000 by key leaders in universities, industry, trade associations, professional societies and political leaders that underline societal implications of nanoscience and nanotechnology:

The Semiconductor Industry Association endorses with enthusiasm the establishment of a National Nanotechnology Initiative (NNI). The semiconductor industry has advanced, and continues to advance at a rapid pace, according to Moore's Law, primarily through scaling, continually reducing the physical dimensions of the devices, and structures that make up the chip. This has led to tremendous growth in productivity in nearly all aspects of the economy, since semiconductors are the fundamental building block of information appliances, which enable us to communicate, calculate, and play. However, in time, the dimensions of the devices will approach the atomic scale, the natural province of nanotechnology. We consider basic research in this area crucially important to keep the economic engine moving forward. We will work with the Administration and Congress to assure that this important initiative comes into being.

**—George Scalise
President, Semiconductor Industry Association**

As we enter the third millennium, I can't imagine a more important technological initiative to undertake than the National Nanotechnology Initiative. The results forthcoming from such an initiative will transform our lives and transform the very concept of manufacturing in ways that it's hard to fathom at this moment in time. The bringing together of atoms and bits raises many provocative technological and scientific questions. I believe that such a long-term initiative will have short, medium and long term impact and will help stretch the national imagination.

**—John Seely Brown
Chief Scientist, Xerox Corporation and
Director, Xerox Palo Alto Research Center**

The National Nanotechnology Initiative (NNI) is an extraordinarily important investment in the future strength of America's economy, industrial base, and scientific leadership. Recent scientific and technical advances have made it possible to assemble materials and components atom by atom, or molecule by molecule. We are just beginning to understand how to use nanotechnology to build devices and machines that imitate the elegance and economy of nature. The gathering nanotechnology revolution will eventually make possible a huge leap in computing power, vastly stronger yet much lighter materials, advances in medical technologies, as well as devices and processes with much lower energy and environmental costs. Nanotechnology may well rival the development of the

transistor or telecommunications in its ultimate impact. Yet it is the first technological revolution since World War II in which the United States has not had an early commanding lead. We must invest now in the basic scientific and technological research, infrastructure, and young scientists and engineers who will drive this new field and create the industries of the future.

—**Charles M. Vest**
President, Massachusetts Institute of Technology

The National Nanotechnology Initiative is a big step in a vitally important direction. It will send a clear signal to the youth of this country that the hard core of physical science (particularly physics and chemistry) and the nanofrontiers of engineering have a rich, rewarding future of great social relevance. The coming high tech of building practical things at the ultimate level of finesse, precise right down to the last atom, has the potential to transform our lives. Physics and chemistry are the principal disciplines that will make this all happen. But they are hard disciplines to master, and far too few have perceived the rewards at the end of the road sufficient to justify the effort. The proposed NNI will help immensely to inspire our youth.

—**Richard E. Smalley**
Gene and Norman Hackerman Professor of Chemistry and Professor of Physics
Rice University Center for Nanoscale Science and Technology

It's hard to think of an industry that isn't likely to be disrupted by nanotechnology.

—**David Bishop**
Lucent Technologies' Bell Labs

This letter is to acknowledge my full support and endorsement for the National Nanotechnology Initiative. I believe that this initiative is very important for the nation, and will assure our continued leadership position in high technology. The encompassing potential for nanotechnology will help to contribute to improved healthcare for the nation, continue our countries industrial and economic growth, and provide new technical solutions for many environmental problems.

—**Michael J. Heller, Ph.D.**
Chief Technical Office, Nanogen Inc.

Having represented the pharmaceutical industry in the PCAST review of the applications of Nanotechnology and its role in the future of the U.S. and Global economy, I should like to add my endorsement of the position presented by the Panel on Nanotechnology. Nanotechnology has the potential for several roles in the Health Care arena:

- Reduction of particle sizes of drug substances to enhance oral availability of new drugs and provide mechanisms to enhance the speed of drug development;

- Development of miniaturized drug delivery systems capable of controlling the release of drugs in a more reliable, time-dependent way than is possible with current technology;
- Development of novel diagnostic technologies for evaluation and identification of diseases within the body;
- Development of higher speed, higher capacity IT systems capable of storing and analyzing the massive amounts of data which will become available on patient genetics, and the potential to use this information for targeting the right drug to the right patient.

The potential applications of Nanotechnology are very significant for future health care, and deserves a focused national effort to develop the fundamental physical, chemical and engineering principles which will fuel its development and application.

—Colin R. Gardner, Ph.D.
Vice President, Pharmaceutical Research and Development, Merck

With the future breakthroughs of nanotechnology, we will be able to make things smaller than a few billionths of a meter. The idea of building machines at molecular scale, once fulfilled, will impact every facet of our lives, such as medicine, health care, computer, information, communication, environment, economy, and many more. Nanotechnology will mandate a highly multidisciplinary approach in education and research, cutting across the boundaries of chemistry, biology, physics, materials, and all aspects of engineering. Our campus and industrial partners applaud the foresight of President Clinton and several agencies lead by NSF on this 2001 federal initiative on “nanotechnology.” We look forward with excitement to resonating to this challenging initiative.

—Henry T. Yang
Chancellor, University of California Santa Barbara

The National Nanotechnology Initiative (NNI) is an important endeavor for this nation to undertake particularly at this juncture of the technology’s development. Without question, nanotechnologies will evolve into one of the most significant technological developments of the early 21st Century having major implications in fields ranging from medicine and health, agriculture, electronics, materials science and pharmaceuticals, to name just a few. In the field of semiconductors, the current technology is approaching the point where fundamental changes will be required to enable the industry’s continuation down the historical “Moore’s Law” path of reducing feature size and cost per bit to achieve continued functional growth — essential to continued productivity gains for the economy. Nanotechnology research represents a promising solution to this challenge, and enables our country to maintain our leadership position in the global high technology race.

Because the foreseeable applications for this technology are perhaps decades away from commercial reality, this basic technology is a classic candidate for federal funding and scientific pursuit. In addition, federal emphasis on nanotechnology through funding grants and scientific research within

government, industry and university laboratories would serve to stimulate interest in science and technology among young men and women at a time when there exists a critical need for such resources in the country.

—**Yoshio Nishi**

Senior Vice President, Research & Development, Texas Instruments Incorporated

There has never been a more crucial time for the U.S. government to support basic research. Besides entering a “Knowledge Age,” we are at the threshold of significant discoveries that will return tremendous economic benefits and radically improve every aspect of our lives. Nanotechnology is arguably one of the most promising of these areas, but one that will require long term research across many disciplines to achieve its full promise. Research in nanotechnology will focus the efforts of biologists, chemists, physicists and materials scientists to yield remarkable new materials and devices for medical diagnostics and treatment, computer technology and information management, and technologies for agriculture and energy production.

I wholeheartedly support the National Nanotechnology Initiative (NNI). It's the right approach at the right time, and it provides educational support that will be the lifeblood of our future scientific progress. We must increase funding now for programs such as NNI if we are to maintain technological leadership in the near future.

—**Paul Horn**

Senior Vice President, IBM Research

The National Nanotechnology Initiative will support atomic, molecular, interface, and nanostructure research applicable to Mississippi State University's strategic research initiatives. These focus on sensor technologies, computational technologies, biotechnologies, and remote sensing, all addressing the agricultural, environmental, and industrial needs in Mississippi.

The sensor miniaturization program in our chemistry department and the simulation, modeling, and visualization capabilities of our Engineering Research Center in Computational Field Simulation provide cross-cutting technologies in support of research and development of sensing systems. These systems have important applications in the areas of environmental pollutants, chemical and biological molecules and proteins, and other nanotechnology structures.

—**Malcolm Portera**

President, Mississippi State University

Nanoscience and technology research at our Engineering Research Center for Biofilms has been crucial to our understanding weak chemical signals in colonies of bacteria that cause a host of diseases such as middle ear infections, prostatitis, and pneumonia in cystic fibrosis. Greater investment in research at the nanoscale will enable us to work on cures.

—**Tom McCoy**

**Acting President, Vice President for Research, Creativity and Technology Transfer
Montana State University**

As Director of Hewlett-Packard Laboratories, I would like to endorse the recommendations of your Committee of Advisors on Science and Technology in their support of the proposed Nanotechnology Initiative. As you may know, HP has been an industry leader in the development of computer technology based upon atomic and molecular structures. The ability to construct machines at the atomic scale will create exciting opportunities for developing new solutions to age-old problems in health and medicine, energy efficiency, agricultural productivity, and in preserving the environment. This development of intelligent, energy efficient and recyclable devices, whose size and weight will be measured in atoms, will likely drive the next wave of economic progress in this country and around the world.

For these reasons, Hewlett-Packard is committed to pursuing opportunities in nanotechnology. We recognize the great opportunities that nanotechnology holds for our country, and therefore we endorse your advisory committee's recommendations that these public policy goals – and their achievement – should be those of the nation as a whole.

—Dick Lampman
Director, Hewlett-Packard Laboratories

As the elected representative of the 13,000-member Materials Research Society, I am writing to enthusiastically endorse the National Nanotechnology Initiative. This relatively new and exciting area of science and engineering holds tremendous promise for discoveries and inventions across a wide variety of areas. We see in nanotechnology opportunities for the development of new knowledge, techniques and devices with applications ranging from medicine to computers and telecommunications to aerospace. The ability to control materials near the atomic level to alter properties, tailor their behavior, and to build unseen devices will bring about a revolution that is currently unimaginable. The multidisciplinary nature of nanotechnology is particularly well-recognized by the MRS, in that our members work in cross-disciplinary arenas including biology, biochemistry, solid state physics, materials science, mechanical engineering, and many more. Their work includes much that is already occurring in the fledgling area of nanotechnology, such as biomimetic structures, nano-scale machines and smart materials. It is expected that the National Nanotechnology Initiative will also provide for the education and training in this area of the scientists, engineers, managers, and leaders of tomorrow. As nano-science and engineering is expected to become another fundamental technology, it is vital that we have both the best-trained practitioners and lay citizenry that must participate in making related social decisions.

Please accept our wholehearted support for the National Nanotechnology Initiative. We are looking forward to working with the President and Congress to build a bipartisan effort to make the Initiative a success.

—Harry A. Atwater
President, Materials Research Society

As President of the 42,000-member American Physical Society, I am pleased to endorse the new federal Initiative on Nanotechnology. The Nanotechnology Initiative will take advantage of extraordinary recent developments in the ability of scientists to work with individual atoms, molecules, and electrons. These new capabilities will lead to a deeper understanding of the fundamental physics of novel atomic and molecular systems and, through this understanding, to a greatly enhanced ability to design new materials and devices. The opportunities for understanding the molecular basis for biological processes are especially exciting. I anticipate that the scientific advances arising from this initiative will revolutionize US industries and sustain our nation's remarkable economic development. Physicists will play key roles in all aspects of the Nanotechnology Initiative. In order to inform our members about this new Initiative, the American Physical Society is planning a special plenary session on nanotechnology at our meeting this March.

—**James S. Langer**
President, American Physical Society

Nanotechnology is clearly a challenging new frontier for industry and industrial R&D, but one that offers unlimited potential for new products, new processes, and new services that will benefit society in ways we can not yet imagine.

—**Charles F. Larson**
President, Industrial Research Institute

I support the initiative because interest in nanomaterials has been rapidly growing for the past several years. More and more customers are coming to us looking to use our nanopowders to either dramatically improve existing products or create new products using these materials.

A thrust from the federal government is required not only to encourage basic research in nanomaterials to get a good understanding of the basic science issues involved, but also to bridge the gap between science on the one hand, and implementation in the real world on the other.

—**Ganesh Skandan**
Vice President for R & D, Nanopowder Enterprises Inc. (Small Business)

As the President of the 10,000 member American Ceramic Society, I am writing to you in support of the National Nanotechnology Initiative. We believe that both the infusion of new funding in support of overall research and development activities, as well as this new initiative, will have a critical impact on the nation's economic growth and global leadership role.

The National Nanotechnology Initiative can have an important impact on broad areas of science and technology and can put us in a clear leadership position in this area (something we currently do not hold). Because this is a relatively new area, one can envision the possibility of numerous advances in materials, chemistry, pharmaceuticals, medicine, electronics, information and computer technologies, etc. As with any new research initiatives, one cannot accurately predict specific future breakthroughs. However, we know from past experiences

that they are the basis for important new technologies and new civilian markets. One need only review the changes brought about by developments that have evolved from advances in communications and information technology; the space, energy, and nuclear programs; and in the areas of genetics and biotechnology.

The real danger is that of our current situation in which our stagnant support for R&D in the physical sciences is leading to a real decay in our technological and scientific leadership. Last fall, ACerS and many other technical materials societies, whose combined membership represent approximately one million members, wrote to individual congressmen asking them to reconsider the need to increase R&D funding. Prior to that, these technical societies had met with congressional leaders to support R&D funding increases. This continues to be a critical issue for this nation.

We fully support the National Nanotechnology Initiative as an extremely step towards the evolution of new technologies and revolutionary scientific discoveries. We further implore the administration and Congress to work together to increase support for all R&D, which continues to contribute to the growth of our nation's economy and technological and global leadership. We of the American Ceramic Society will strive to provide our support and leadership as we need towards these ends.

—Paul F. Bechter
President, The American Ceramic Society

Having first hand research experience in the field of nanotechnology, I would like to endorse the position presented by the panel on nanotechnology. Nanotechnology has excellent potential in revolutionizing Health Care industries. The reduction in size of pharmaceutically active ingredients should increase the stability and bioavailability of the drug. The nanodrug delivery systems will have extraordinary feature such as targeted ultracontrolled release of drugs, vis-a-vis, existing drug delivery systems. The nanobiomaterials have opened new opportunities in designing superior biocompatible coatings for the implants at a molecular level. The National Nanotechnology Initiative (NNI) is a very important investment for future growth of American economy and scientific leadership. We applaud the initiative taken by President Clinton and several other federal agencies on this topic of vital national interest.

—C. P. Singh, Ph.D.
President, Nano Interface Technology, Inc. (Small Business)

The Executives Committees of the Division of Materials Physics and the Division of Condensed Matter Physics of the American Physical Society enthusiastically endorse the National Nanotechnology Initiative. We represent approximately 7,500 professional physicists, including many who are leaders in this emerging area of research.

The ability developed over the last decade to manipulate and study materials at the nanometer length scale offers possibilities for advances in science and technology whose potential impact is so vast that we are only just beginning to get a glimpse of it. We are at a time in the development of this technology

similar to the early '90's when the Internet was emerging. Nanotechnology offers enormous potential for discovering new fundamental science, for creating new materials with unique and important properties, and for developing new technology. Recent discoveries include an electronic device based on a single molecule, manipulation of biocellular function via synthetic nanocrystal insertion, and nano-scale sensors able to detect environmental conditions with unprecedented accuracy. The impact will be felt in nearly every area of technology, from information storage and processing, to medicine, to remote sensing, to automobiles and telephones. The impact on fundamental science is equally broadbased, from new tools to measure X-rays from distant galaxies to measuring the properties of individual electrons in semiconductors. In addition, we believe that the ability to visualize and manipulate atoms and molecules will capture the public's imagination and inspire a new public commitment to teaching and learning science.

Development of nanoscale science and technology is dependent on progress in an extraordinary wide range of fields, including physics, chemistry, materials science, biology, and engineering. It underlies a new unity in science where progress often depends on a multidisciplinary approach, and where a technological or scientific advance in one field can create extraordinary opportunities in another.

A strong investment by the nation in nanotechnology will lay the intellectual and technical foundation for sustained advances in cutting edge science, innovative technology, and economic competitiveness over the next quarter century. Nanotechnology is the next great frontier, with challenges and opportunities that will extend our reach and enrich our lives. As physicists, we stand ready to work together with other scientists and engineers to develop the promise of nanotechnology. We welcome the scientific challenges and the technological opportunities. We believe that the National Nanotechnology Initiative will bring unprecedented rewards to our society.

—**Frances Hellman**

Chair, APS Division of Materials Physics

—**Richard A. Webb**

Chair, APS Division of Condensed Matter Physics

Letter from Dean D. Allan Bromley sent to President Clinton:

Dear President Clinton:

There are few, if indeed any, areas of science or technology that will not be profoundly changed by the introduction of nanotechnology. For this reason, the National Nanotechnology Initiative is of fundamental importance to our economic competitiveness, to our national security, and to the quality of our lives. As yet, we have only glimpsed the dramatic impact that nanodevices can have in extending or repairing deficits in the human senses, in increasing the sensitivity of our measurements, and in expanding the scope and power of both communications and computations. The Initiative is particularly important in that it will build and strengthen the necessary science and technology infrastructure across the U.S. at research centers and institutions, to keep us at the forefront of this vital new technology. We were slow to appreciate its potential

and slow to invest in its development. By coordinating fundamental research investments by the more than 15 federal agencies interested in nanotechnology, the Initiative will ensure maximum possible returns in new knowledge and in young minds trained to use that knowledge in innovative and creative fashion for each tax dollar spent.

Nanotechnology is the sixth truly revolutionary technology introduced in the modern world following the Industrial Revolution of the mid-1700s, the Nuclear Energy Revolution of the 1940's, The Green Revolution of the 1960's, The Information Revolution of the 1980's, and the Bio Technology Revolution of the 1990's.

—D. Allan Bromley
Former Assistant to The President of the United States
for Science and Technology (1989-1993)

Nanotechnology, the science of developing tools and machines as small as one molecule, will have as big an impact on our lives as transistors and chips did in the past 40 years. Imagine highly specialized machines you ingest, systems for security smaller than a piece of dust and collectively intelligent household appliances and cars. The implications for defense, public safety and health are astounding.

—Newt Gingrich
Former Speaker of the U.S. House of Representatives
(*Washington Post*, October 18, 1999, “We Must Fund the Scientific Revolution”)

As the President of The Minerals, Metals, and Materials Society (TMS) I am writing to enthusiastically endorse the National Nanotechnology Initiative. We represent 10,000 professional materials scientists and engineers, some of whom will certainly be leaders in such a national effort. In fact TMS 10 years ago recognized this as one of the potentially most important unexplored frontiers in materials science. As a consequence TMS began holding a series of symposia in the area for university, industry, and government research laboratory scientists to become educated and excited by the possibilities presented by materials having some characteristic nanometer dimensionality. Between then and now exciting “glimpses” of novel properties, unusual property combinations, and new phenomena have been uncovered in such materials. However, much more remains to be answered. For instance, in most cases it is still not known whether the novel properties are a consequence of new physics at the nanometer scale or just the logical extension to small dimensions of large scale phenomena. A focused national effort is just what is required in order for this area to be explored at a faster rate: US industry, national security, and public health can then capitalize on the discoveries of the last 15-20 years, e.g. in taking advantage of findings like the “giant magnetoresistance effect” in nanolayered thin films, which is revolutionizing the magnetic storage industry. Since existing measurement tools are working at their limits to examine such materials, new devices and equipment need to be developed and a large cadre of students need to be trained in their use. Cross-disciplinary research needs to be encouraged and

fostered; and seed money for testing innovative ideas needs to be available. A National Nanotechnology Initiative should accomplish this. . . . TMS, a materials society, is wholeheartedly behind this National Initiative because we see this as THE direction of the future in materials research.

—**Y. Austin Chang**
President, The Minerals, Metals and Materials Society

This new technology is very exciting and might lead to discoveries that will change the way almost everything, from building materials to vaccines to computers, are designed and made. . . . Research in nanotechnology is extremely important to future rates of innovation in the country. Innovation is the key to our comparative advantage in the global economy, yet federal investment in the physical sciences that help drive innovation - math, chemistry, geology, physics, and chemical, mechanical, and electrical engineering - are all declining, as are the number of college and advanced degrees in these areas.... It is vitally important that we increase our investment in the physical sciences, including nanotechnology, if we are to see increases in productivity and incomes in the years ahead.

—**Senator Evan Bayh (D-IN)**
U.S. Senate Science and Technology Caucus Roundtable Discussion, April 5, 2000

Virginia's Center for Innovative Technology (CIT) enthusiastically endorses the National Nanotechnology Initiative (NNI). It is a critical investment in the future strength of America's economy, industrial base, and scientific leadership.

Currently, researchers at universities, companies, and federal labs in Virginia are active in such applications of nanotechnology research as aerospace, biotechnology, communications, electronics, information technology, and advanced manufacturing. The NNI will help Virginia continue to contribute to critical breakthroughs.

Nanotechnology requires a multidisciplinary and collaborative approach in research and industry. Our academic and industrial partners join CIT in expressing the importance of this initiative to the future of the Commonwealth of Virginia and America.

—**Anne Armstrong**
President, Virginia's Center for Innovative Technology

Nanotechnology sounds like something that's almost science fiction. It's a word that's easy to think is not a real tangible policy. Well, what nanotechnology means to the average citizen is: will it be able to identify a cancer when it's one cell large?

It's the kind of breakthrough that will open doors to science and health research that are closed if we don't invest in nanotechnology. With a surplus and a time of economic well being in the country we have the ability, and I would say we have the obligation, to invest in that kind of forward-looking research. That's why the president put those proposals forward, it's why we're fighting very hard as the

Congress considers our budget request for those priorities. We're going to stick to our guns, and we're going to keep insisting on better funding in these areas, because we believe it's very important.

—**Jack Lew**
Director, Office of Management and Budget
July 5, 2000, National Press Club

Nanotechnology is another very important NSF program. Nanotechnology refers to the ability to manipulate individual atoms and molecules, making it possible to build machines on the scale of human cells or create materials and structures from the bottom up, building in desired properties. Nanotechnology is at an exploratory state. The Nanotechnology Initiative at NSF will fund over 600 projects and 2500 faculty and students, fund 10 large engineering research and materials research centers and 5 university-based research hubs. These efforts will, among other things, help create the knowledge required to address the fast approaching physical limits to semiconductor performance.

—**Senator Trent Lott, Senate Majority Leader**
Letter to Senate High-Technology Task Force, August 2000

We started the last century with the industrial revolution and ended it with the information revolution. Now, at the beginning of the 21st century, we are on the verge of a new revolution — THE NANOTECHNOLOGY REVOLUTION.

What is nanotechnology? Why do I believe it is the science and technology that will drive the future? Nanotechnology is the science of creating new materials and devices on the atomic and sub-atomic level through the manipulation of individual atoms and molecules. In Nanotechnology, we are poised to take the next major leap into the future where the possibilities are endless.

.....

Now, the time is right to establish Nanotechnology as an urgent national priority. Last year, President Clinton released a blueprint and a budget for a National Nanotechnology Initiative. This blueprint, created by an inter-agency working group, is one of the least noted and most important documents of the Clinton Administration.

—**Senator Barbara A. Mikulski**
Wernher von Braun Lecture at NASA Headquarters, June 12, 2000