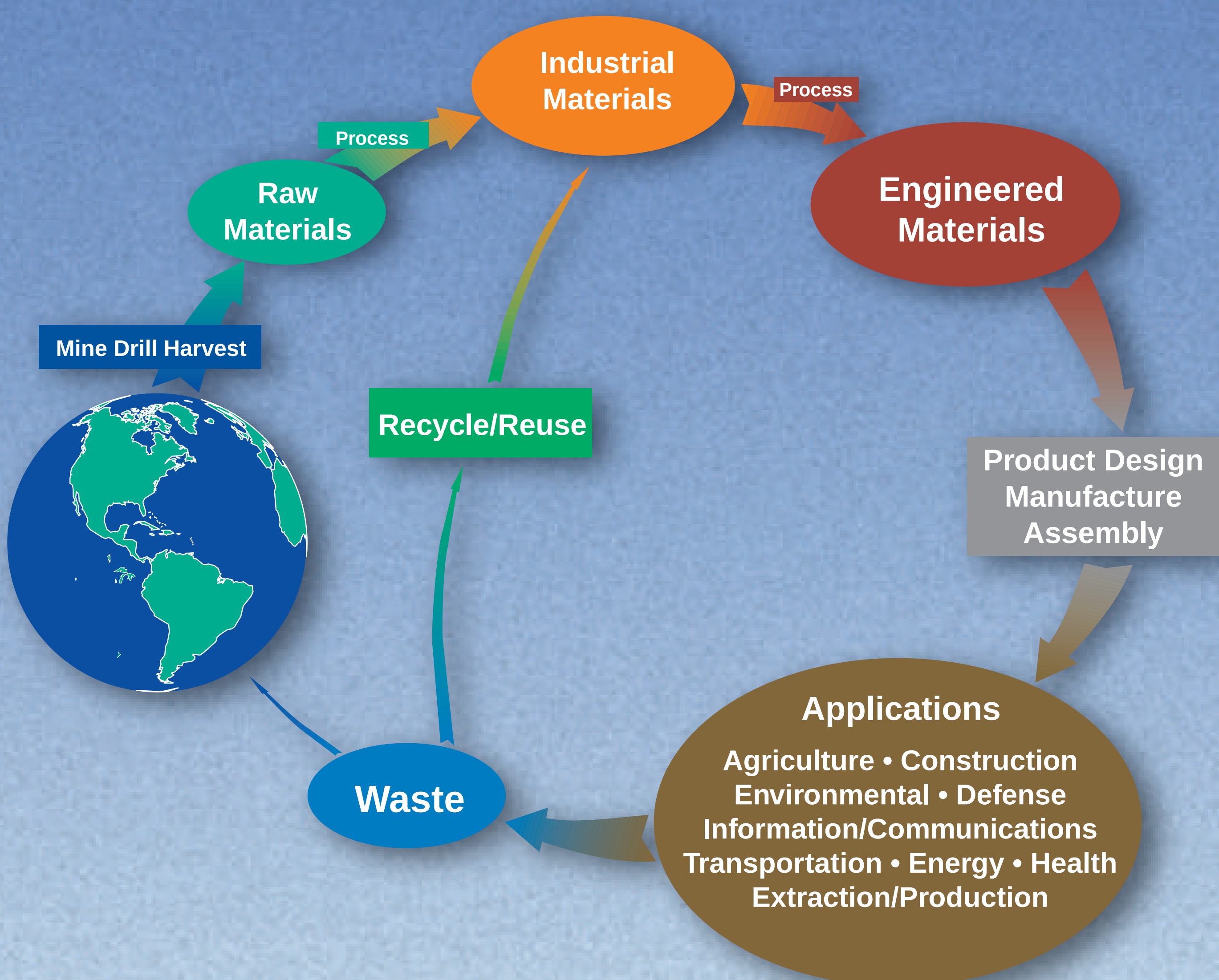
1995

THE FEDERAL RESEARCH AND DEVELOPMENT PROGRAM IN MATERIALS SCIENCE AND TECHNOLOGY

EXECUTIVE OFFICE OF THE PRESIDENT OF THE UNITED STATES
NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

Total Materials Cycle
The Pathway for Technology Advancement



Total Materials Cycle

The Pathway for Technology Advancement

Materials are pervasive in practically all manufacturing technologies, in the physical and engineering sciences, and in everyday life. The ubiquitous character of materials is reflected by the total materials cycle. The earth is the source of all materials as well as the ultimate repository. Minerals, ores, and oils are taken from the earth, and crops harvested. Through purification, refining, conditioning, and other processes these raw materials are converted into useful industrial materials -- metals, ceramics, and polymers, for example. In subsequent processing, these bulk industrial materials are modified into engineered materials that meet specific property and performance requirements. The engineered materials then are manufactured into parts, which are assembled to make a useful end product. Once its useful life is over, the product eventually is returned to the earth as waste, or it is dismantled and the materials recovered to feed into the cycle all over again.

The stages of the materials cycle are interdependent, in that any step taken in any part of the cycle may have effects elsewhere in the cycle. New pathways around the cycle open up continually as a result of basic research and development that lead to novel engineered materials, new applications, and innovative manufacturing processes for factory operations.

The materials cycle, thus, is a visual representation of the various processing stages materials must pass through in the development and production of products and technologies. At each stage, quality increases and economic value is added, and associated costs are incurred, thereby establishing the market worth and competitive edge.

1995 Federal Research and Development Program in Materials Science and Technology

A Report by the Materials Technology Subcommittee
Committee on Civilian Industrial Technology
National Science and Technology Council

Executive Office of the President
Office of Science and Technology Policy

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About the National Science and Technology Council

President Clinton established the National Science and Technology Council (NSTC) by Executive Order on November 23, 1993. This cabinet-level council is the principal means for the President to coordinate science, space, and technology policies across the Federal Government. NSTC acts as a "virtual" agency for science and technology to coordinate the diverse parts of the Federal research and development enterprise. The NSTC is chaired by the President. Membership consists of the Vice President, Assistant to the President for Science and Technology, Cabinet Secretaries and Agency Heads with significant science and technology responsibilities, and other senior White House officials.

An important objective of the NSTC is the establishment of clear national goals for Federal science and technology investments in areas ranging from information technologies and health research, to improving transportation systems and strengthening fundamental research. The Council prepares research and development strategies that are coordinated across Federal agencies to form an investment package that is aimed at accomplishing multiple national goals.

To obtain additional information regarding the NSTC, contact the NSTC Executive Secretariat at 202-456-6100.

About the Office of Science and Technology Policy

The Office of Science and Technology Policy (OSTP) was established by the National Science and Technology Policy, Organization, and Priorities Act of 1976. OSTP's responsibilities include advising the President in policy formulation and budget development on all questions in which science and technology are important elements; articulating the President's science and technology policies and programs, and fostering strong partnerships among Federal, State, and local governments, and the scientific communities in industry and academe.

To obtain additional information regarding the OSTP, contact the OSTP Administrative Office at 202-395-7347.

THE WHITE HOUSE

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Advanced materials form the basis of manufactured products in industries that directly support hundreds of thousands of jobs. The associated processing technologies are essential to continued development of cutting-edge military and commercial products. While the United States has led the world in science and development of advanced materials, it often has lagged in commercializing these materials. Effective development and commercialization of advanced materials is critical to maintaining and improving our competitiveness in world markets and providing Americans with high-quality jobs.

The Federal Government has invested in materials research and development (R&D) for nearly a century, providing a foundation for many commercial and military components. The Federal investment in materials R&D is substantial and diverse. This document is a comprehensive look at the current Federal materials R&D effort, the role of materials in industrial competitiveness, and an assessment of how materials R&D relates to national priorities. The materials R&D programs of nine Federal departments and agencies are described and points of contact are provided to facilitate collaboration among the public and private sector members of the broad materials R&D community.

This report was prepared under the auspices of the National Science and Technology Council (NSTC) by the Materials Technology Subcommittee of the NSTC's Committee on Civilian Industrial Technology.

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Executive Summary

The Nation's economic prosperity and military security depend heavily on development and commercialization of advanced materials. Materials are a key facet of many technologies, providing the key ingredient for entire industries and tens of millions of jobs. With foreign competition in many areas of technology growing, improvements in materials and associated processes are needed now more than ever, both to create the new products and jobs of the future and to ensure that U.S. industry and military forces can compete and win in the international arena.

The Federal Government has invested in materials research and development (R&D) for nearly a century, helping to lay the foundation for many of the best commercial products and military components used today. But while the United States has led the world in the science and development of advanced materials, it often has lagged in commercializing them. This long-standing hurdle must be overcome now if the nation is to maintain its leadership in materials R&D and the many technologies that depend on it.

The Administration therefore seeks to foster commercialization of state-of-the-art materials for both commercial and military use, as a means of promoting U.S. industrial competitiveness as well as the procurement of advanced military and space systems and other products at affordable costs.

The Federal R&D effort in Fiscal Year 1994 for materials science and technology is an estimated $2123.7 million. It includes the ongoing R&D base that support the missions of nine Federal departments and agencies, increased strategic investment to overcome obstacles to commercialization of advanced materials technologies, interagency cooperation in R&D areas of mutual benefit to leverage assets and eliminate duplicative work, cost-shared research with industrial and academic partners in critical precompetitive technology areas, and international cooperation on selected R&D topics with assured benefits for the United States.

The materials R&D program also supports the Administration's specific technological objectives, emphasizing development of affordable, high-performance commercial and military aircraft; ultra-fuel-efficient, low-emissions automobiles that are also safe and comfortable; powerful yet inexpensive electronic systems; environmentally safe products and processes; and a durable building and transportation infrastructure.

1. The Role of Materials in Industrial Competitiveness

The Role of Materials in Industrial Competitiveness

Advanced materials are the foundation and fabric of manufactured products. Advanced materials provide robust structures for fuel-efficient automobiles and damage-resistant buildings, enable electronic devices to transmit signals rapidly over long distances, protect bridges and other surfaces from wear and corrosion, and endow jet engines and airframes with sufficient strength and heat tolerance to permit supersonic flight. Without advanced materials, many of today's leading commercial products and military systems would not exist. And without further development and commercialization of advanced materials, many potential products of tomorrow -- critical to the Nation's continued prosperity -- will never come to be.

Materials establish and support entire industries. Tens of millions of manufacturing jobs depend on the availability of advanced materials at affordable costs. For example, the U.S. steel industry gave rise to the domestic automobile industry, which today includes the largest manufacturing company in the world. Similarly, the U.S. aluminum industry enabled the rapid development of high-performance commercial and military aircraft, which remain among the few positive contributors to the U.S. balance of trade. Now, the future prosperity of both the automobile and aircraft industries may depend on further development and commercialization of composite materials, which are lighter than metals but still too expensive for widespread use.

Other examples of materials-based products and industries abound. The essence of the $56 billion worldwide semiconductor electronics market is silicon, which provided the foundation for the technological revolution of the past 40 years and remains essential to the circuitry in many high-value products, including aircraft, automobiles, and information systems. Now, in the face of intense foreign competition, continued U.S. competitiveness in microelectronics depends on processing and packaging advances that will push silicon technology to its performance limits, as well as atom-by-atom engineering of new materials with specific insulating, light sensitivity, and other properties.

Materials are thus "enabling" technologies, contributing to the success of diverse technological systems, which in turn drive economic growth and safeguard national security. Technology always has been a driver of high-wage job creation and a steady rise in living standards. Today, with the end of the Cold War, the globalization of the world economy, and the proliferation of new information and manufacturing systems, technology is more powerful than ever as a mechanism for raising productivity and assuring world-class industrial and economic performance. The rapid technological transformation of many industries further heightens the need for materials research and development (R&D), which is critical in areas of changing technology [1].

New generations of commercial materials will enable advances in the functionality, economy, and durability of many technologies and thereby assist the Nation in meeting the rapidly changing demands of society and industry entering the 21st century. The United States traditionally has led the world in *developing* advanced materials but often has lagged in *commercializing* them. Now, continued development and increased commercialization of advanced materials cannot wait; if the United States fails to meet these challenges, then other nations will assume leadership of the world of materials and the many industries that depend on it.

For these reasons, materials R&D for industrial applications is among the priorities of the National Science and Technology Council (NSTC), which coordinates all Federal R&D programs and policies and works with agencies to set budget priorities. The NSTC, which is

Advanced materials are the most recent, engineered developments within a materials class. The term encompasses both improved versions of natural resources and other traditional materials, as well as new materials and combinations developed in the laboratory.

chaired by the President, seeks to respond to industry needs and promote wealth generation while also pursuing activities that support national priorities, such as national security and environmental protection.

To assist in achieving NSTC objectives, this report describes the Federal materials R&D program. Timely dissemination of such information is one means of promoting the rapid application of new materials, in that it helps minimize duplication of research and allows industrial and academic researchers to anticipate the arrival of particular materials and assess their commercial potential [2].

This report was produced by the Materials Technology (MatTec) subcommittee of the NSTC Committee on Civilian Industrial Technology (CCIT)[1]. The emphasis, therefore, is on R&D linked directly to industrial applications, particularly in the national priority areas of aeronautics, automotive technology, electronics, environmental technology, and infrastructure. However, because applied research both depends on and contributes to fundamental knowledge, this report covers all Federally supported materials R&D, including basic research coordinated by NSTC committees other than CCIT and MatTec.

[1] Function statements and membership rosters for CCIT and MatTec are provided in Appendix A.

2. The Federal Materials R&D Effort

The Federal Materials R&D Effort

Defining and Coordinating The Federal Role

Federal agencies have invested in materials R&D since the early 1900s. Historically, advanced materials originated primarily in the defense and aerospace sectors, which depended heavily on Federal contracts. The government thus assumed the high risk and expense of moving materials to the commercial stage. But today, with defense budgets declining and military costs inflated, it is the private sector that drives technological advancement. Even so, government investment remains crucial where the costs of investing in new technologies are high and the rewards are both distant and diffused across many companies.

By fostering commercialization of state-of-the-art materials, the Federal Government both promotes industrial competitiveness and ensures the military's ability to specify and procure advanced military and space systems at affordable costs. For example, development of advanced composites that are sufficiently low in cost for mass commercial applications, such as automobiles, will benefit industry while also ensuring the availability of such materials for defense use. The NSTC emphasizes dual-use technologies, including advanced materials, which have both civilian and defense applications.

The focus on industrial applications has been encouraged by the National Research Council, which has recommended that, to provide as broad an "application window" as possible, the Federal R&D program address commercial materials needs [2]. The CCIT is responsible for that aspect of the program, coordinating all Federal R&D efforts that promote industrial competitiveness and economic growth in national priority areas, such as those illustrated by Table 1. Materials R&D oversight is the responsibility of MatTec, which seeks to couple these activities with industry needs while also eliminating duplication in Federal programs and leveraging resources through interagency collaboration. This effort continues the recent trend toward increased cooperation among Federal agencies and with the private sector, as documented in previous inventories of Federal materials R&D [3][4][5].

The Federal Investment in Materials R&D

The Federal investment in materials R&D[2] is substantial and diverse, encompassing many types of materials and related processing techniques developed or employed by a broad range of industrial sectors. The program addresses virtually every aspect of the materials cycle (depicted on the front cover of this document). The materials under study include biomaterials; ceramics; composites; metals; polymers; and electronic, magnetic, optical/photonic, and superconducting materials. These classes of materials are defined in Appendix B.

The overall Federal effort supports both the missions of individual agencies and NSTC goals. Basic research is designed to expand scientific understanding of materials and related processes. Applied research focuses on developing new or improved materials for specific Federal mission or industrial applications. At present, special emphasis is placed on helping industry overcome obstacles to commercialization of advanced materials (these barriers are summarized in Appendix C).

[2] Materials R&D is defined broadly here as scientific and engineering research on substances in any form, at any stage of preparation, fabrication, or manufacture.

Table 1: Examples of advanced materials applications in national priority areas

Area → / Material ↓	Aeronautics	Automotive	Electronics	Environmental Technologies	Infrastructure
Bio-materials	lubricants	lubricants	DNA-based computing systems	oil spill cleanup technologies	construction products
Ceramics	armor packaging	fuel-efficient engines	electronic packaging materials	catalytic converters	building insulation
Composites	low-cost propulsion systems	lightweight body panels	printed wiring boards	efficient power-generation systems	advanced building and bridge construction
Electronic materials	advanced radar systems	process control sensors	long-range cellular phones	emission control sensors	"smart" buildings
Magnetic materials	propulsion system bearings	efficient electric motors	audio-visual devices	waste separation systems	advanced auto warning systems
Metals	affordable supersonic airframes	low-cost titanium components	high-density data storage	pollution avoidance processing	aluminum bridge decks
Optical/ photonic materials	enhanced cockpit vision devices	gauge panel displays	energy-efficient flat panel displays	emission displays	traffic control sensors
Polymers	lightweight airframes	lightweight components	insulation	starch-based degradable plastics	durable road pavement materials
Super-conducting materials	electronic control systems	advanced motors and flywheels	miniature super-computers	efficient energy storage devices	magnetic levitation for vehicle guideways

Table 2: Examples of Federally supported materials-related R&D topics in national priority areas*

Area → / Agency ↓	Aeronautics	Automotive	Electronics	Environmental Technologies	Infrastructure
DOC	metal alloy casting process models and sensors	manufacture of polymer-matrix composites	advanced packaging materials	assessment of low-emissions industrial chemicals	prediction of concrete performance
DOD	low-cost composites for propulsion	low-cost structural composites	sensors for "smart" structures	low-emissions paints and coatings	non-destructive evaluation methods
DOE	lightweight and intermetallic alloys	welding and joining of metals and ceramics	studies of thin films and semi-conductors	high-efficiency solar energy conversion cells	low-cost, corrosion-resistant materials
DOI	n/a	lightweight metals processing	mining safety	materials waste minimization and cleanup	long service-life materials
DOT	fire-safe aircraft cabin interiors	crash-worthiness of new materials	luggage surveillance systems	use of recycled materials in pavement	lightweight aluminum for bridges
HHS	n/a	n/a	body implants	health monitors	n/a
NASA	supersonic airframe materials	low-cost titanium processing	new heat-sink materials	low-noise, low-emissions engines	aircraft control sensors
NSF	fatigue and fracture studies of composites and metals	preparation and shaping of polymers and composites	basic research on nanoscale materials	environmentally conscious manufacturing	advanced cement-based materials
USDA	n/a	wood/plastic composites for auto interiors	n/a	fuels from biomass	durable timber bridges

* n/a means the agency is not active in the area

Nine Federal agencies support materials R&D activities[3] in areas of national importance (see examples in Table 2):

- Department of Commerce (DOC)
- Department of Defense (DOD)
- Department of Energy (DOE)
- Department of the Interior (DOI)
- Department of Transportation (DOT)
- Department of Health and Human Services (HHS)
- National Aeronautics and Space Administration (NASA)
- National Science Foundation (NSF)
- U.S. Department of Agriculture (USDA)

The Federal R&D effort in Fiscal Year (FY) 1994 for materials science and technology is an estimated $2123.7 million. It includes the ongoing R&D base that supports Federal department and agency missions, increased strategic investment to overcome obstacles to commercialization of advanced materials technologies, interagency cooperation in areas of mutual benefit to leverage assets and eliminate duplicative work, cost-shared research with industrial and academic partners in critical precompetitive technology areas, and international cooperation on selected R&D topics with assured benefits for the United States.

Table 3 shows the budget breakdown by agency. The largest program is supported by DOE, followed by DOD and NSF. Table 4 provides budget data for two major complementary programs that support cost-shared industrial R&D in key topic areas, including materials. These programs are described in the Section, Partnerships with Industry, of this chapter.

The R&D activities are conducted in diverse locations, including government-owned, government-operated laboratories; government-owned, contractor-operated laboratories; and, through grants and contracts, at industrial, university, and private research centers. Research results are shared among agencies through mechanisms such as the Federal Laboratory

TABLE 3

MATERIALS R&D EXPENDITURES BY AGENCY
Dollars in Millions

Agency	FY93 (Actual Expenditures) $M	FY94 (Actual Expenditures) $M
DOC	53.4 (36.9)	56.6 (41.8)
DOD*	563.0	545.0
DOE*	987.7 (695.5)	911.4 (623.7)
DOI	24.9	21.5
DOT	14.9	12.7
HHS	85.9	91.9
NASA**	102.8	131.1
NSF	303.6 (276.0)	310.6 (282.5)
USDA	37.4	42.9
TOTAL	2173.6 (1837.3)	2123.7 (1793.1)

Parentheses indicate expenditures excluding construction and operating costs for major national user facilities

* Excludes classified research and development
** NASA's budget data taken from a FY 1994 document [5]

[Note: Due to year-end budget recision legislation, FY 1995 expenditures were not available at the time this document went to press.]

TABLE 4

COMPLEMENTARY MATERIALS R&D PROGRAM FUNDING
Dollars in Millions

Program	FY93 $M	FY94 $M
Advanced Technology Program (ATP)	1.9	4.0
Technology Reinvestment Program (TRP)	5.0	37.0

[3] The Environmental Protection Agency, which was included in previous inventories of Federal materials R&D, now reports its activities through the NSTC Committee on Environment and Natural Resources Research.

Consortium, which includes representatives from all national laboratories.

Program types vary widely. A project may be conducted as either a discrete or a multi-component activity clearly identified as materials research, or as a subset of a program with an unrelated title. The activities may be part of a technology development effort, such as the multi-agency Partnership for a New Generation of Vehicles (PNGV); a device or process development activity such as DOD's affordable composites for propulsion programs; a data project such as DOC's database on characteristics of environmentally safe chemicals; or individual projects conducted either to advance fundamental understanding or for their intrinsic intellectual interest, such as some of those sponsored by NSF.

All agencies collect information that can be used in evaluating R&D programs, including materials-related activities. The types of data collected may vary, depending on an agency's mission, the nature of the activities undertaken, and the mechanisms and goals of R&D projects. Examples of current metrics are provided in the adjacent sidebar; formal programmatic evaluation efforts have been initiated[4]. Illustrations of how Federal support contributes to commercial innovation are provided in additional sidebars throughout this report.

How Agencies Measure R&D Accomplishments

Federal materials R&D program are evaluated in various ways [6]. For example, DOC data show that researchers in the Materials Science and Engineering Laboratory (MSEL) published an average of over three papers each in FY 1993, and that MSEL papers are cited frequently by other scientists. (MSEL's archival publications on the structure of high-temperature superconducting materials are among the 100 most-cited papers in the United States.) Another type of measure is emphasized by DOD, which routinely collects data on the economic benefits of materials R&D. For example, a new cooling fluid developed for aircraft electronic systems solved problems with system clogging and electrical arcing; savings for the Air Force B-1B and F-18 aircraft alone are estimated at $1 billion. The DOE employs numerous measures, including "grades" issued by the Office of Program Analysis for some 230 materials science programs during the past three years.

Partnerships with Industry

U.S. companies invest heavily in materials technology, particularly as it relates to the manufacture of new or improved products. However, industrial R&D typically addresses one company's immediate needs rather than advanced materials and processes or the filling of critical gaps in the Nation's technological leadership. Due to anti-trust concerns and a reluctance to share innovations that might offer a competitive advantage, companies rarely cooperate to define materials needs or support joint R&D programs addressing new materials or applications. Furthermore, some materials industries, such as titanium producers, which have been essential to the success of U.S. aerospace programs, are in decline; without assistance, they cannot afford the R&D needed to modernize or expand markets for advanced materials.

These limitations and many others must be overcome -- and they can, through the combined efforts of industry and government, a central theme of NSTC activities. Industry brings to the table critical market expertise in selecting areas for technology investment. Government can

[4] For example, an interagency working group is measuring the impact of all Federal R&D on technology commercialization. Two types of measures will be used: process measures of technology transfer, such as numbers of joint projects involving government laboratories and industry, and Federal revenues from licensing; and measures of economic impact, such as jobs created. Meanwhile, DOE is developing performance measures specifically for basic research in materials science. Metrics under consideration include risk taking, originality, creativity, innovation, numbers of peer-reviewed and invited journal papers reporting original research results, numbers of invited lectures at professional meetings or institutions, and numbers of cooperative R&D projects with industry.

provide a long-term outlook, support for fundamental research that benefits broad sectors, and support for activities with potentially high payoffs that are too risky for industry. Importantly, government can act as a facilitator and convene groups to address problems that individual companies cannot solve alone.

Federal support and mechanisms for public-private R&D partnerships have multiplied over the past decade. In an effort to leverage scarce resources and maximize research success, there has been a growing emphasis on technology transfer from Federal laboratories to the private sector, and on collaborative R&D for precompetitive technology development. Principles governing these partnerships include

- industry leadership;
- cost sharing;
- protection of intellectual priority rights
- competitive selection, on the basis of merit, for cost-shared projects;
- evaluation of joint programs to determine their success; and
- termination of programs once goals are accomplished.

There are many funding mechanisms for collaborative research. Individual agencies award grants and contracts to industrial and academic researchers to carry out or assist with R&D activities related to agency missions. Industry may contribute personnel, services, or equipment.

Collaborative R&D also is carried out through consortia, which can be tailored to the needs of particular industries. The model is SEMATECH, an industry consortium that receives resources from major electronics companies and matching DOD funds to develop semiconductor manufacturing technology. The consortium contracts with the government to carry out the overall R&D effort through cost-share agreements. The consortium then subcontracts the actual work to appropriate consortium members or to supporting industry base players. Many similar consortia focusing on diverse topics have been established in recent years.

Cooperative Research and Development Agreements (CRADAs) also are increasingly popular. This type of research agreement was established as a mechanism for technology transfer in 1986 for government-operated laboratories, and in 1989 for government-owned, contractor-operated labs. Projects are proposed by industry, which shares the costs by providing direct funding and, in some cases, supplies and equipment. Federal labs contribute their share of support in the form of expertise and technology.

Computer Model Improves Metal Engine Parts Processing

A computer model developed through a DOC consortium has helped optimize the processing of jet engine parts and thereby improved the manufacturer's competitiveness. Crucible Compaction Metals, a small Pennsylvania company, makes metal disks that rotate at high speed to move gas through jet engines. Given the corrosive, high-temperature environment of these engines, the disks must be made of tough, reliable material in an affordable manner. Crucible's manufacturing process starts with molten metal alloy, which is converted into a fine powder through inert gas atomization. The powder then is loaded into metal molds and consolidated into parts through hot isostatic pressing. The process, which requires little machining or finishing, is efficient in theory, but Crucible's powder particle size was often too big. The company then joined the National Institute of Technology's (NIST) powder metallurgy consortium, which helped develop a computer model using data obtained from NIST's supersonic inert gas metal atomizer. By employing this model to optimize the process, the company increased the percentage of useable powder by over 40 percent while also reducing consumption of argon gas and overall operating costs.

Federal agencies established a total of more than 4,000 CRADAs in 1994. The growing popularity of CRADAs can be attributed to recent efforts to simplify and improve the process. The government has developed model agreements with pre-approved terms and conditions and is working with industry to find the appropriate technical capabilities within the Federal R&D complex, to define partnerships that address the most important problems, and to establish improved metrics to measure the outcomes and impacts of CRADAs.

Finally, a growing number of Federal programs enhance private-sector R&D efforts, including materials-related activities. The major programs include the following:

The Advanced Materials Synthesis and Processing Partnerships Program, run by DOD's Advanced Research Projects Agency (ARPA), works with industrial consortia to advance dual-use technology objectives in strategically important areas of electronics and photonics. Topics of interest include "smart" materials and structures, and organic thin-film materials for opto-electronic technologies.

The Advanced Technology Program, a cost-shared program that supports multi-year development of a broad spectrum of high-risk, potentially high-payoff commercial technologies, including advanced materials and materials-dependent systems. Awards are made in a general competition and in focus areas selected based on input from industry. One current focus area is manufacturing of polymer-matrix composites for large, commercial structural applications, such as automobiles and bridges. New focus areas for 1995 include materials processing for heavy industry. The program is run by DOC.

The Alternative Agricultural Research and Commercialization Center supports cost-shared, private-sector R&D designed to expedite development and market penetration of industrial (nonfood, nonfeed) products made from agricultural and forestry materials. The overall objective is to bridge the gap between research results and commercialization. Most clients are small firms, with preference given to projects that benefit rural communities and are environmentally friendly. The program is run by USDA.

The DOE Center of Excellence for the Synthesis and Processing of Advanced Materials is a new distributed (virtual) center linking investigators from 12 national laboratories, universities, and industry. The initial R&D topics are metal forming, materials joining, nanostructured materials for energy applications, microstructural engineering with polymers, tailored microstructures in magnets, processing for surface hardness, and corrosion protection coatings.

The Energy Related Inventions Program offers one-time support for development and commercialization of energy-related concepts, devices, products, materials, or processes. The goal is to help generate economic benefits from non-nuclear energy technologies developed by inventors and small businesses. More than 400 proposals have been funded since 1975. The program is run by DOE with the participation of DOC.

The Industry Technology Program, a new cost-shared program in which industry-led teams adapt and develop new technologies for applications in aerospace and other commercial sectors. Based at NASA, the program supports high-risk research with strong potential for yielding commercial benefits and strengthening the competitiveness of U.S. industry.

The Manufacturing Extension Partnership (MEP), a national network of services and extension centers that provides technical and business support to the Nation's 350,000 small and medium-sized manufacturers. The goal is to help these firms, some of which make or use advanced materials, modernize production capabilities and become more competitive. The Administration plans to expand the number of MEP extension centers to 100 by 1997. Run by DOC, the program has linkages to DOD, DOE, and other Federal agencies.

The National Research Initiative, administered by USDA, offers competitive grants to individuals or teams of academic researchers addressing issues of the highest priority in agriculture, forestry, and related sciences.

The National User Facilities provide specialized laboratories and equipment -- many unique in the Nation and the world -- to industrial and academic materials scientists who otherwise would not have access to these advanced tools. The facilities, which are operated by DOC, DOE, and NSF, are described in Chapter 4, National User Facilities.

The Small Business Innovation Research (SBIR) program fosters innovation in the private sector by awarding contracts to small companies for commercialization of results from Federally supported R&D activities. Universities may participate. Eleven Federal agencies are involved. Many projects involve materials R&D, such as development of advanced lightweight materials for automotive applications.

The Small Business Technology Transfer (SBTT) pilot program awards contracts for joint R&D projects involving small businesses and research institutions. Like its parent SBIR program, SBTT funds activities designed to commercialize the results of Federally funded R&D. Five agencies participate: DOD, DOE, HHS, NASA, and NSF.

The Technology Reinvestment Project (TRP) promotes development and deployment of new dual-use technologies for both civilian and military applications. The goal is to provide both the most advanced, affordable military systems and the most competitive commercial products. The program stresses cost-shared partnerships among government laboratories, industry, and universities. Based at ARPA, the TRP is a joint effort of six agencies (DOC, DOD, DOE, DOT, NASA, and NSF) and the largest multi-agency technology development effort ever conducted by the Federal Government.

International Competition and Cooperation

International competition and cooperation are essential, interrelated aspects of materials R&D. As stated in a previous report on this subject, competition "provides the impetus for technical advance and new markets and is the essence of business strategy and success", while cooperation is needed "to provide the combined technical and financial resources to ensure an international technical base for free trade and national productivity growth" [1].

Competition and cooperation across national boundaries are particularly important today, because technology has become an international commodity, and state-of-the-art technology is a linchpin of both industrial competitiveness and military strength. In the global marketplace, both U.S. firms and the U.S. military must have access to leading-edge technologies, whether developed domestically or overseas. But access to materials-related technologies has been diminishing, due to erosion of U.S. leadership in many areas of materials R&D and the historical failure to obtain reciprocal benefits from foreign beneficiaries of U.S. research.

There is ample documentation of the strong challenges to U.S. technological leadership. For example, the National Critical Technologies Review Group recently concluded that the United States remains the world leader in materials by a slight margin but is losing ground to Japan and Europe [7]. According to this report, the U.S. lead is most secure with respect to stealth materials (special coatings and designs that reduce the signature of weapons systems) and remains substantial in metal alloys, composites, and aircraft structural materials. The picture is mixed with respect to superconductors and ceramics. More disturbing, the United States is not only behind but also losing ground in electronic/photonic materials. (It is no coincidence that the U.S. electronics industry as a whole is struggling, particularly in the areas of optical information storage, multichip packaging systems, and display technology.)

The erosion of U.S. technological leadership can be attributed to a number of historical factors, including low government support, relative to Europe and Japan, for commercially critical precompetitive R&D[5]; lack of a coherent approach to monitoring and reporting on science and technology developments in other nations; and a one-way flow of advanced technologies from the United States to other countries. Not long ago, a committee of experts warned that the United States "has yet to adopt strategies, structures, or mechanisms to defend its declining leadership in the world of materials" [1].

The logical remedies include increased Federal support in critical precompetitive R&D areas, formal monitoring of foreign developments in science and technology, and international cooperation on selected R&D topics with assured benefits for the United States. While the Administration is pursuing all three approaches[6], the third one -- cooperation -- is most relevant in the present context, because it involves R&D planning and implementation (the subject of this report), and it can be accomplished without increased spending in an era of shrinking Federal budgets. Indeed, cooperative R&D, whenever and wherever employed, saves money by leveraging assets and eliminating the need for duplicative work.

The United States has a history of limited R&D cooperation with other nations, particularly with respect to defense technologies. What is new is the emphasis on securing equitable reciprocal benefits. Historically, the United States has shared considerable expertise and technology with its military allies; now, cooperation is pursued as a means of securing U.S. military access to state-of-the-art technologies. The gains from splitting development costs with partners and from interoperability of systems are expected to exceed by a wide margin the incremental costs of overcoming language, cultural, and institutional differences.

An example of such a cooperative effort is a major DOD initiative aimed at gaining access to Japan's dual-use commercial technologies, manufacturing knowhow, components, and subsystems. The effort seeks to balance the significant amounts of U.S. defense technology that flow to Japan with a compensating flow of dual-use technologies for use in U.S. military applications. The emphasis is on fostering company-to-company linkages. DOD also has proposed joint development of military systems with North Atlantic Treaty Organization allies. In addition, as part of the effort to shift the focus of weapons laboratories to development of dual-use technologies, DOE's Los Alamos National Laboratory, along with U.S. industrial partners, is developing mutually beneficial relationships with scientific institutions in the former Soviet Union. For example, U.S. development of advanced techniques for ceramic sintering and joining have been based on Russian high-power, high-frequency gyrotron technology.

A number of other international R&D arrangements established by individual Federal agencies may lead to advances in commercial technologies. Research on lithium-containing ceramics, the media for breeding tritium fuel for fusion energy systems, has been conducted by DOE in collaboration with Japan and Canada. Researchers have fabricated and studied the irradiation response of various candidate ceramic materials, including lithium oxide, lithium zirconate, lithium silicate, and lithium aluminate. Fusion energy is seen as an eventual means of eliminating U.S. reliance on imported oil.

Another joint effort involving DOC and Japan addresses a broader range of materials. Eleven cooperative R&D projects have been initiated and 27 more are being considered by a Joint Working Level Committee on Advanced Materials, established under the U.S.-Japan Science and Technology Agreement signed in 1988. Current topics include development of a database on high-temperature superconducting materials, studies of high-strength conductive materials and their application to high-field magnets, research on amorphous and microcrystalline semiconductors, and synthesis

[5] The United States spends only 1.9 percent of its gross national product on non-military R&D, compared to 2.7 percent in Germany and 3 percent in Japan [8]. The German and Japanese governments have special divisions devoted to sponsorship of industrial, academic, and public-private R&D related to national objectives.

[6] With regard to the first two approaches, the Clinton Administration has made technology policy a key element of its economic strategy and has increased the Federal investment in commercially significant R&D, while the DOC is expanding its program devoted to translating and disseminating technical information originating in Pacific Rim and European nations [9].

of high-purity diamond from the vapor phase. Apart from DOC, the U.S. participants are all at universities.

In addition, the United States and a number of Central and Eastern European countries[7] support joint research under bilateral science and technology agreements. These efforts are intended to advance foreign policy goals, promote U.S. competitiveness, and resolve transnational environmental problems. The joint funding provides grants for research in a wide range of fields, some of which, such as mining, involve the use, separation, and/or processing of materials.

Finally, the United States is increasing its participation in and promotion of efforts to develop international standards -- classification systems, terminology, specifications, and test methods -- for advanced materials. These activities benefit the Nation in two ways. First, international standards promote commerce and free trade by fostering technology transfer and interoperability of systems and helping to assure that poor product quality, whether actual or perceived, does not become a trade barrier. Second, it is to any country's advantage to have its own standards adopted at the international level, thereby avoiding the costs and time required to change domestic standards. Indeed, a direct correlation has been observed between U.S. participation in international standards activities and U.S. export levels. The DOC, which works with U.S. industry to develop and apply standards domestically, also guides the Nation's efforts in the international arena.

Many of these activities are carried out through the International Organization for Standardization (ISO), a worldwide federation of standards-setting bodies. Of 166 ISO technical committees, 35 address materials, generally those considered traditional rather than advanced. Standardization of advanced materials, because they are new and complex, remains at a preliminary stage. To promote development and use of innovative materials, the United States participates in the Versailles Project on Advanced Materials and Standards (VAMAS)[8], which conducts a wide range of pre-standardization studies, tests, and development efforts through 19 technical working groups. VAMAS products include a unified classification system for advanced technical ceramics, which have highly tailored microstructures that are useful in applications ranging from high-heat engine components to corrosion-resistant biomedical implants.

[7] The countries involved are Croatia, the Czech Republic, Hungary, Macedonia, Poland, and Slovenia.

[8] Other participants in VAMAS, which recently established a formal cooperative relationship with the ISO, are Canada, France, Germany, Italy, Japan, the United Kingdom, and European Community (EC).

3. Materials R&D Related to National Priorities

Materials R&D Related to National Priorities

Aeronautical Materials Technologies

For many years, U.S.-made aircraft have dominated the international arena because of their exceptional performance. But today, performance is no longer enough. The future of the U.S. aerospace industry now depends on affordability -- the capability to make commercial jets, military fighters, and helicopters with state-of-the-art features at affordable costs. Affordability, in turn, hinges in large part on development and manufacturing of advanced airframe and engine materials that cost less than today's varieties.

Advances in aeronautics will be critical to the future prosperity of the United States. The aeronautics industry (civil and military combined) is the single largest positive contributor to the U.S. balance of trade, with a 1993 trade surplus of over $23 billion. The industry also provides more than 900,000 high-paying American jobs, despite recent layoffs tied to declines in military spending and the economic recession. Yet, with foreign competition from Europe and Asia increasing, the U.S. aircraft industry is losing market share, already down from 80 percent of the civil aircraft market in 1970 to less than 60 percent today [10]. Similar trends are evident in the propulsion industry, which has lost 20 percent of the global market in commercial turbofan engines over the past 10 years. Aerospace exports declined by over 12 percent in 1993, after eight straight record-high years.

The long-range prospects for worldwide growth in civil aviation are enormous, with world passenger traffic expected to nearly triple by 2015. But the U.S. aeronautics industry has been slow in restructuring to capture this market and respond to global trends, due in part to its lengthy product development cycle, low product volumes, and constrained market conditions. There are also many technical barriers to the industry's growth.

To help strengthen the U.S. aerospace industry and foster development of more efficient and affordable next generation of aircraft, the NSTC's Aeronautics Materials and Manufacturing Technologies (AMMT) Working Group was formed to conduct a coordinated interagency assessment of industry needs and Federal investment in these technologies. The AMMT, which reports to both CCIT and the NSTC Transportation Committee, has undertaken a number of planning activities that reflect a new approach to Federal aeronautics R&D.

In the past, advances in aeronautical materials technology have been driven by individual agencies, primarily DOD and NASA, working with specific companies to improve performance. The industry sought advanced technologies principally to gain the performance advantages critical to product competitiveness. Now, materials and manufacturing technologies are playing increasingly important and sometimes enabling roles in affordable production while, at the same time, providing performance advantages.

With affordability now the major driver in both civil and military aeronautics, technological advances are needed on multiple fronts. To meet this challenge, cooperative efforts will be needed involving multiple government agencies, industry, and academia. Industry, which previously influenced R&D programs through contract research, now works with a number of Federal agencies to identify needs and develop R&D plans. The Federal materials effort continues to be led by DOD and NASA, with participation by DOC, DOE, DOT, and NSF.

Seven AMMT task groups were formed to assess aeronautical technology needs ranging from subsonic airframe technologies to materials and process standardization to education and training. The AMMT Working Group obtained input from the aeronautics industry and universities through an industry-led workshop and a government-industry conference, and the working group has recommended a set of national goals aimed at improving the economic well-being and international competitiveness of the U.S. aeronautics industry and its supporting industry base.

Military and commercial aircraft producers, as well as their supporting industry base, are involved in the cooperative R&D. Flexibility is essential in developing R&D arrangements because this industry makes a wide range of products with equally diverse requirements, and some segments of the industry are in poor financial condition. Because of the concurrent downturn in defense spending and commercial aircraft orders, most U.S. airframe and engine manufacturers, and especially their supporting industry base, cannot afford the amount of cost sharing required in government-industry research and technology partnerships.

The specialty materials industry is a crucial segment of the aerospace industry that has been especially hard hit by limited commercial markets and declines in military spending. The materials involved include aluminum, carbon-polymer composites, metallic superalloys, and titanium. The recovery of this industry will depend on development of non-aerospace products and markets through reductions in processing costs, modernization of titanium and superalloy processing methods, and reinstatement of manufacturing process R&D that has been eliminated by industry for economic reasons.

The Technical Program

The aeronautics industry produces and uses a complex, interwoven amalgam of countless technologies. Materials are integral to both product design and manufacturing processes. To achieve affordability, researchers must reduce the high cost of some aerospace materials (such as titanium), develop high-quality databases for prediction of materials life-cycle performance, and establish lean manufacturing processes that includes statistical process control. In addition, materials must be better integrated into manufacturing processes through increased standardization as well as use of computer-aided design and process simulations, and nondestructive evaluation.

Many ongoing Federal programs, both broad and focused, address the U.S. aeronautics industry's technology needs. Such programs include NASA's Aeronautics Research and Technology Base, High-Speed Research, and Advanced Subsonic Technologies programs; DOD's Lean Aircraft and Joint Advanced Strike Technologies initiatives; and ARPA's Affordable Aircraft Acquisition, Affordable Composites for Propulsion, and Titanium Metal-Matrix Composites for Propulsion programs. The AMMT efforts build on these programs in realigning priorities.

The R&D addresses two broad categories of aircraft:

Subsonic aircraft include commercial aircraft and helicopters and military helicopters, transports, and patrol/bomber aircraft. The AMMT objectives are to increase airline profitability by increasing aircraft productivity and reducing ownership and operating costs. At present, less than 2 percent of Federal aeronautics R&D is focused on subsonic airframes, compared to 31 percent for governments in Europe. Problems to be resolved include the high risk of introducing a new product (which typically will not generate a net return for at least seven years), Federal investments that are not synchronized with industrial product development cycles and are spread thin over too many programs, and erosion of the materials supplier base.

Supersonic commercial transport aircraft, envisioned as a means of capturing the long-haul Pacific Rim market and creating 140,000 U.S. jobs, pose a unique challenge because they would cruise at speeds up to Mach 2.4 (almost 2.5 times the speed of sound) more frequently and for longer time periods than do advanced military aircraft. Supersonic aircraft must be able to tolerate the consequences of very high temperatures and yet meet the affordability demands of commercial customers. Roadblocks include the lack of knowledge about how to apply lean production and agile manufacturing in the aircraft industry, the extensive work required to characterize the effects of the supersonic environment on properties of polymers and metals, the weak supplier base for titanium and composites, and a lack of manufacturing simulation technology.

AMMT Goals and Research Issues

The AMMT Working Group focused on assessing the needs for structural materials and manufacturing technologies for airframes and propulsion systems in support of the national goal to "maintain the superiority of U.S. aircraft and engines" identified in "Goals for a National Partnership in Aeronautics Research and Technology." The scope includes materials and processes, design and analysis methods, fabrication and assembly techniques, inspection and test methods, and integrated design and manufacturing technologies. Four supporting goals were identified:

Develop and validate low-cost design and manufacturing technologies for affordable metallic airframe structures.

Today's airframe manufacturing process was developed for riveted aluminum skin-stringer technology, a concept dating to the 1940s. The U.S. is not yet developing lightweight, low-cost, damage-tolerant metallic alternatives to conventional construction, even though these technologies could provide weight savings of up to 15 percent and cost savings of up to 30 percent.

Programs are needed to develop advanced metallic structural concepts and manufacturing approaches that take advantage of conventional and advanced materials, process models and advanced sensors for on-line monitoring and control, advanced damage tolerance analysis and optimization tools, and low-cost tooling concepts. Reductions in cost and weight would boost the competitiveness of subsonic commercial and military transport and rotorcraft industries as well as the commuter and general aviation industries and, over the long term, would reduce the cost of future high-speed commercial aircraft.

Standardize procedures for developing advanced materials and process specifications, analysis methods, and design data.

Development and use of standardized specifications and design data could have numerous benefits. First, it could reduce the cost of materials qualification and certification, which can amount to over 20 percent of total structural design costs. Second, it could foster market diversification and transfer of advanced materials technologies to non-aerospace industries. By broadening the applicability of advanced materials, specifications would help retain the defense-critical supplier base, reduce the risk of using new materials, and shorten time to market.

Specifications for conventional metallic materials and processing methods are available, but little data has been collected on advanced alloys, composites, or ceramics. Standards are needed for materials and processes, test methods, structural design and analysis methods, and design and quality criteria. Some data-collection efforts are under way but they are not coordinated.

The standardization issue must be addressed if the aeronautics industry is to achieve the types of efficiencies demonstrated in, for example, the automotive and electronics industries. Procedures for development of design data also would improve the U.S. negotiating position in development of international standards that could benefit domestic producers. Cooperative standards setting will be required, involving government certification agencies, military handbook developers, technical societies and standards bodies, materials suppliers, and manufacturers of advanced materials.

NASA research in advanced materials and processing in partnership with other government agencies and industry can give the United States a technological advantage in the international market for a new generation of supersonic airlines.

Develop affordable composite airframe structures.

Composite airframe structures can offer substantial weight and cost savings relative to state-of-the-art aluminum structures. Composite materials already are used in primary structures of military aircraft, but affordability is a problem with respect to commercial applications. A major effort is needed to scale up and validate the affordable manufacturing technologies needed to bridge the gap between engineering and production, in order to reduce the risk of using composites in commercial production and accelerate the use of polymer-matrix composites in primary airframe structures. Such an effort also would lay the groundwork for affordable production of future high-speed commercial airframe structures.

Improve the performance and quality and reduce the cost of aircraft turbine engines.

Both the Federal Government and industry conduct considerable aircraft propulsion R&D, but these efforts must be integrated more effectively than they are now, with an emphasis on affordability and commercialization. The United States has a store of propulsion materials technology, such as titanium-based metal-matrix composites and magnetic bearings, which has yet to be converted to affordable usage in actual production. A national road map is needed that identifies gaps in commercialization.

Processing advances are essential to reduce the cost and enhance the performance of existing materials (e.g., aluminum, titanium, nickel, cobalt) for applications such as rotating structural components. Analytical tools, databases, and models must be developed to facilitate design for performance and affordability. Also needed is an infrastructure of broad utility that can produce a variety of materials from a materials family.

New materials must be designed as well. Engine efficiency could be improved through development of novel materials, such as composites and intermetallics, that are more heat tolerant than today's nickel-based superalloys. Propulsion system durability and/or efficiency could be improved through development of nanostructured materials and coatings, which can provide order-of-magnitude improvements in strength, wear resistance, and thermal heat rejection capabilities.

Evaluation

The major initial accomplishment of the AMMT was the establishment of a successful interagency government-industry planning process. The process has served as a model for the national planning activities of the broader Aeronautics and Aviation Subcommittee of the NSTC Committee on Transportation R&D. This Subcommittee is conducting a detailed assessment of the Federal investment in aeronautics and aviation R&D and is developing interagency plans and programs for achieving the national goals described in the NSTC report "Goals for a National Partnership in Aeronautics Research and Technology." Success ultimately will be measured by the impact of the joint R&D

Gelcasting to Reduce Costs of Ceramic Engine Parts

A low-cost process developed by DOE for making large, complex ceramic parts has been licensed for commercial production of aircraft engine components. Initially developed in the late 1980s, gelcasting is a near-net shape forming process that produces complex parts with uniform densities that can be machined before firing. In the past, ceramic parts could be formed only through machining, a costly and time-consuming process. Apart from reducing these costs, gelcasting also requires less material and can produce different kinds of parts than does the traditional approach. An additional benefit is ease of implementation; gelcasting uses conventional ceramic processing equipment and represents a minimal departure from standard manufacturing practice. Allied Signal Ceramic Components Company recently worked with DOE's Oak Ridge National Laboratory to demonstrate the use of gelcasting to manufacture silicon nitride turbine wheels for aircraft engines. Allied Signal subsequently licensed the technology for commercial production.

activities on the economic well-being and competitiveness of the U.S. aeronautics industry and its supporting industry base. However, because it may take years to commercialize any new hardware or technology resulting from AMMT efforts, it will be difficult to measure the impact of the R&D on the industry's competitiveness in the near term.

Automotive Materials Technologies: Partnership for a New Generation of Vehicles[9]

The vision of the Partnership for a New Generation of Vehicles (PNGV) has been described as even more ambitious than putting a man on the moon: Development by the year 2003 of a family-sized sedan that travels 80 miles per gallon (mpg) of gasoline -- yet costs the same and offers as much comfort, performance, and safety as today's family sedan, all while meeting current emissions and materials recycling standards.

Realization of the PNGV vision will depend heavily on further development and commercialization of advanced lightweight structural materials. The automobile industry uses 23 million tons of materials annually. The weight of the materials used in vehicle body panels and other parts has a strong influence on fuel economy; the lighter the materials, the lower the energy and power requirements for accelerating, maintaining speed, and braking. A 10 percent reduction in vehicle mass increases the mpg rating by over 5 percent. Consequently, PNGV researchers are looking for ways to redesign cars and replace conventional steel with either high-strength steel or lightweight composites, aluminum, or magnesium. Related efforts are under way to improve powertrain efficiency through advances in materials and materials processing as well as other technologies.

The potential economic, energy, and environmental benefits of the partnership are considerable. The major beneficiaries will be automobile-related industries, which now account for over 7 million jobs and about 5 percent of the U.S. gross domestic product. Achievement of PNGV goals (see sidebar) would improve the competitiveness of these industries in international markets and create new U.S. jobs. The Nation would benefit from overall reductions in gasoline consumption and environment-damaging emissions. In addition, advances in vehicle manufacturing will have broad applicability to other manufacturing sectors, thereby further boosting the U.S. economy.

U.S. automakers play the primary role in executing the PNGV technical agenda, working through the U.S. Council for Automotive Research (USCAR), which facilitates and promotes cooperative R&D addressing precompetitive technologies. A number of consortia operating under the USCAR umbrella also contribute to the PNGV, and participation is open to materials suppliers, universities, individuals, and others. Industry facilities and expertise are used in most process feasibility demonstrations, process engineering, component fabrication and testing, and pilot-scale demonstrations.

PNGV Goals

The PNGV is a unique partnership of the Federal Government and General Motors Corp., Ford Motor Co., and Chrysler Corp. Formed in 1993, the PNGV is addressing three interrelated goals:

Goal 1: Develop advanced manufacturing techniques that will help move new automobiles and components into the marketplace quickly and thereby improve U.S. industrial competitiveness.

Goal 2: Pursue technological advances that can lead to near-term improvements in the fuel efficiency, safety, and emissions of standard vehicles.

Goal 3: Develop a prototype production vehicle that can achieve up to three times the fuel efficiency of today's family-sized sedan.

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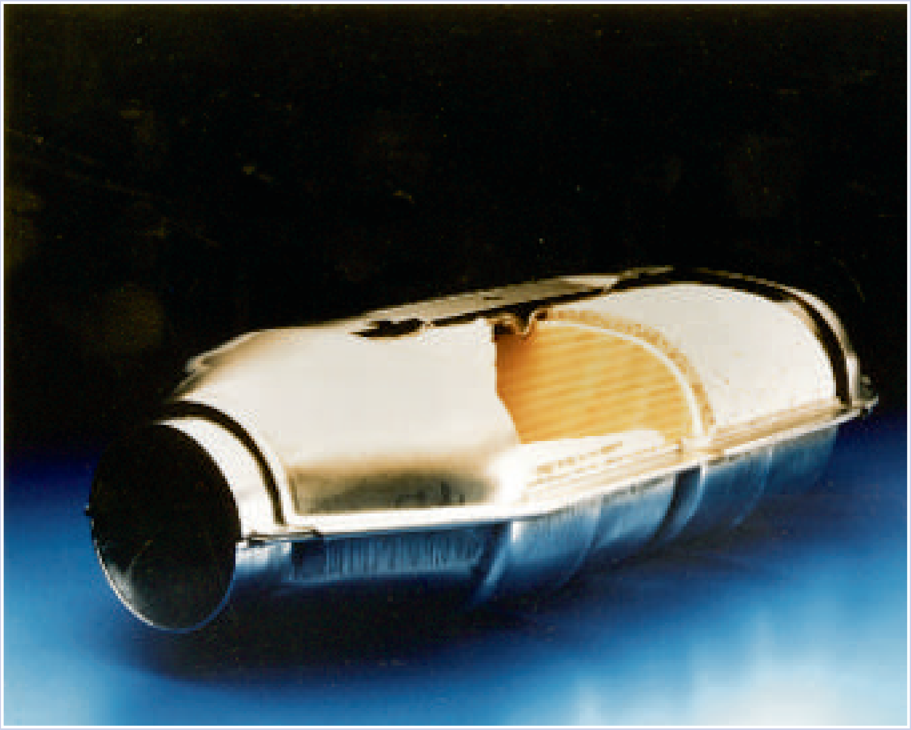
[9] Additional information about the PNGV is available in a number of reports [11,12,13].



Ceramic Regenerator Matrix/Catalytic Exhaust Converters for Automobiles and Heavy Duty Engines

The DOE ceramic turbine and materials programs are responsible for spawning an entirely new industry. Early ceramic regenerator development provided the materials technology for a catalytic converter now commonly used to reduce automobile emissions. A program with Ford Motor Co. to solve the corrosion and reliability problems of ceramic regenerators for a heavy-duty gas turbine engine led Corning Inc. to develop the magnesium-aluminosilicate (MAS) extruded honeycomb catalyst support used in practically all gasoline-engine powered automobiles today. Current sales are $600 million per year worldwide and growing rapidly. Other component sales are projected at $1 billion for the year 2000, accounting for 10,000 jobs.

The role of government laboratories is to provide pre-competitive R&D support in material design and process modeling, material characterization, fabrication, database generation, recycling technologies, and test method determination. Elements of the Federal program are coordinated closely with, and in many cases performed by, the auto industry. Federal agencies may use a variety of mechanisms, including CRADAs, to carry out PNGV-related research in cooperation with the private sector.

Six Federal agencies are involved in PNGV-related materials R&D activities: DOC, DOD, DOE, DOT, NASA, and NSF. Related projects also are carried out by industrial and academic researchers through a number of Federal programs, including the Advanced Technology Program (ATP), Energy Related Inventions Program, Small Business Innovation Research program, and Technology Reinvestment Project (TRP). The ATP and TRP particularly are expected to provide significant support for technology development activities that will contribute to achievement of PNGV goals.

Several symposia, attended by participants from government, industry, (including materials suppliers) and universities, have been held to examine critical PNGV technology areas. At the first symposium, R&D objectives, metrics, and timing were confirmed. The second meeting focused on basic research needs, including lightweight materials. The third symposium addressed structural materials challenges, which are summarized in the present report. Other materials-related issues will be addressed in future symposia.

The PNGV Technical Program

The PNGV technical program focuses on long-term, high-risk enabling R&D activities identified by industry as essential to the development of advanced lightweight materials for energy-efficient and cost-competitive automobiles. Advanced lightweight materials and processing technologies will contribute to the achievement of all three PNGV goals, particularly Goal 3. Non-materials R&D activities are not addressed here.

Many scientific and practical issues must be resolved before advanced materials can be applied to reduce vehicle mass substantially while maintaining an affordable, safe structure. Many promising materials are available. But materials innovations involve considerable risk for auto manufacturers, so researchers must come to understand fully the effects of new materials and processes on automobile crashworthiness, durability, aging, lifetime performance, and other requirements. In addition, there are needs for new niche materials, such as high-modulus fibers to strengthen composites, and high-strength, cost-effective resins that increase stiffness.

New and improved processing and manufacturing methods also are needed. In particular, costs must be reduced. The auto industry must be able to mass-produce engineered materials and automotive components of the required quality and durability, using cost-effective and environmentally conscious methods. Automated processes for making composite parts, sensors to ensure the integrity of metal spot welds, new modeling and simulation tools, and many other technologies are needed to enable the affordable use of advanced materials in cars. Finally, automotive systems using new materials must be designed holistically. Researchers will explore the relationships between materials synthesis and processing, and between design and fabrication, in order to optimize the engineering performance of components and systems.

Industrial PNGV teams have identified five broad challenges for materials R&D: weight savings, raw materials costs, manufacturing costs, vehicle safety issues (accurate prediction of material behavior in a crash), and recycling.

Key Materials and Issues

Automobile weight reductions can be achieved in two areas -- the body and chassis, and the powertrain (engine and drivetrain). The targets are a 50 percent reduction in body and chassis weight, and a 10 percent reduction in powertrain weight. Following is a summary of the materials of interest and the major R&D issues that must be addressed.

Body Materials

Lightweight materials such as aluminum, magnesium, metal-matrix composites, polymers, and polymer-matrix composites have been developed and used successfully by the defense and aerospace industries. In those applications, however, the focus has been on performance and reliability rather than cost. If U.S. automakers are to use such materials and remain competitive, then materials processing and manufacturing costs must be reduced. Advances in multiple technology areas will be needed to reduce the costs of these materials so they can be used in automobiles.

Major efforts will be required to develop enhanced processing and manufacturing techniques for lightweight metals; processing and manufacturing methods for lightweight, high-strength materials, such as polymer and metal-matrix composites and structural ceramics; recycling technology for in-plant and scrapped vehicle waste; and robust analysis and design methods that can optimize designs and reduce engineering development time.

The initial focus of PNGV activities will be on low-density metals, such as aluminum and magnesium; metal-matrix composites; polymers and polymer-matrix composites; and joining technology (including adhesives) for use with lightweight metals and composites. In addition, supercomputers will be used to optimize design, performance, material use, and tooling for the manufacture of individual components, subsystems, and complete vehicle systems. Supercomputers also can be used to evaluate vehicle safety and crashworthiness prior to actual fabrication.

The three leading candidate materials for body panels are advanced steels, aluminum/magnesium, and graphite-reinforced composites. Each has benefits and drawbacks. Steel is the least expensive and is completely recyclable, but it is not clear whether an optimized steel vehicle could meet weight reduction targets. Aluminum is sufficiently lightweight and its behavior in crashes can be predicted, but it costs about 50 percent more than steel, and the cost can vary widely with the commodity market. Graphite-reinforced composites weigh even less than aluminum, but many technical breakthroughs would be required to reduce the high costs of carbon fiber and manufacturing processes and to make recycling feasible.

Powertrain Materials

The PNGV research program encompasses a variety of efforts to improve vehicle fuel efficiency with advanced propulsion systems, such as fuel cells, advanced batteries, and equipment that can recover and reduce energy lost in braking. Some projects involve development of advanced materials and associated processing technologies.

For example, one way to reduce the cost of fuel cells -- super-efficient power sources used in the space program that convert chemical energy into electrical and mechanical energy -- would be to replace the graphite now used in machined parts with coated metal or carbon-composite materials. Similarly, the efficiency of electrical systems could be improved through the development of improved, low-cost magnetic materials for electric drive motors and actuators.

Materials that appear especially promising for use in advanced powertrains include ceramics, polymers, composites, and catalytic materials. Initial R&D activities will focus on cost-effective ceramic materials and manufacturing technology; ceramic, polymeric, and catalytic materials for fuel cells and high-power batteries; low-density metals such as aluminum, magnesium, and titanium; and advanced ceramics that will reduce weight and friction and improve thermal performance in conventional engines.

Prospects Improving for Lightweight Composite Cars

NIST researchers, working with a research consortium involving General Motors Corp., Ford Motor Co., and Chrysler Corp., are developing computer models and protocols that will help improve processing of advanced composites for automotive applications. Lightweight yet strong and durable, composites are leading candidates to replace some of the steel in automobiles and aircraft. These composites consist of polymers, such as urethanes, and glass fibers, which probably will be either pressed or woven and braided into mats. Dry mats then will be placed into molds of car components, and liquid resin or other ingredients will be injected so as to permeate the mat. Then, the mold will be heated, initiating a chemical curing process that creates a fiber-reinforced polymeric part. To help ensure the reliability of this process and avoid the time and expense of surprise problems later on, NIST is developing computer models that predict critical process conditions, such as how quickly the liquid resin flows. NIST also is examining materials properties and recycling issues. This assistance has saved industry considerable time and expense and has improved prospects for the use of composites in both cars and aircraft.

Evaluation

Overall progress and performance of the PNGV will be assessed annually by an independent review panel operating under the auspices of the National Research Council. A systems analytic approach will provide technical metrics and overall technical guidance. A schedule of milestones has been developed for the materials R&D projects.

Development of data sets for prototype lightweight steel, aluminum, and composite vehicles is to be completed by mid-1997. At that time, the focus of R&D efforts will be narrowed to only the most promising technologies. Development of concept vehicles, which will establish functional benefits and demonstrate hardware in a systems context, is expected by the year 2000. Production prototypes are expected by 2003.

Metrics for measuring progress toward overall PNGV goals are:

Goal 1: industry adoption and successful use of new manufacturing technology, reduced development time, increased vehicle recyclability, increased market share for U.S. automakers, and maintained long-term profitability for the industry;

Goal 2: reduced emissions levels; reductions in total energy consumption per mile driven; maintenance of vehicle size, performance, and utility; and maintained or improved safety level;

Goal 3: increased overall efficiency of power source and power train and increased recyclability; and reduced vehicle energy demand, aerodynamic drag losses, weight, rolling losses, energy losses, auxiliary power requirements, and emissions.

Qualitative metrics include the degree to which: Federal agencies work together to develop integrated, interagency program planning to increase the efficiency of resource use; government and industry work together in mutually supportive ways to advance technology development; streamlined ways of doing business are implemented to accelerate research activities and; the PNGV advances the technologies that fulfill related legislative mandates (i.e., the Energy Policy Act of 1992, the National Competitiveness Technology Transfer Act of 1989, and the Alternative Motor Fuels Act of 1988).

Electronic Materials Technologies

The future of the electronics industry lies in development of powerful but low-cost technologies such as handheld supercomputers, long-distance wireless communications systems, and energy-efficient flat panel displays. Development of such technologies will depend heavily on materials R&D. A central challenge is to improve the quality and properties of electronic materials as well as the nonreactive materials used for device packaging and interconnection. At the same time, cost-effective techniques must be developed for atom-by-atom design, characterization, and manufacture of these advanced materials.

At stake is the well-being of the U.S. electronics industry and the many other sectors that need its products. The driver of the technological revolution of the past 40 years, electronics is among the largest U.S. manufacturing industries and a key contributor to national security and a wide range of other endeavors. One F-16 fighter jet, for example, has 17,000 electronic components. Whether the objective is to improve the design, manufacture, and operation of a vehicle or to increase the efficiency and reduce the cost of transmitting hospital or military records, electronics are essential to the processing, handling, and interpretation of data.

Although electronics is expected to be one of the fastest-growing industries worldwide in the next 20 years, present trends in the United States are disturbing. Some 32 percent of electronics products purchased in this country during 1993 were imported -- representing approximately 600,000 potential but unrealized American jobs. Because electronics imports have been growing rapidly, the number of potential jobs not realized is expected to top 850,000 annually by the year 2000[10]. Of further concern is the small U.S. share (8 percent) of the global semiconductor materials market. The reasons for the difficulties facing the U.S. electronics industry are complex, but one recurring problem has been failure to commercialize discoveries by U.S. researchers.

In response to this international challenge, the industry-led National Electronics Manufacturing Initiative (NEMI)[11] was established to promote development of the technology and infrastructure required to manufacture advanced electronics products in the United States. The overall goal is to help U.S. companies regain leadership in high-volume manufacturing of electronic products for home and business, and to ensure that the world's best electronics technologies are available to U.S. armed forces at affordable cost. NEMI activities encompass product, process, and infrastructure technologies applicable to the design, manufacture, and testing of products that sense, process, store, and communicate information.

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[10] These data were compiled by the Electronics Industry Association, based on DOC statistics.

[11] Related information may be found in other reports [14,15,16].

Federal R&D efforts, including an Electronic Materials Working Group (EMWG) formed to support CCIT's MatTec and Electronics subcommittees, have been realigned to accommodate the needs of and suggestions made by the electronics industry. The government's role in this cooperative effort is to support science and technology programs that promote domestic manufacture of information systems. Private-sector investment will bring the resulting products to market. The combined effort emphasizes the role of original equipment manufacturers but focuses resources on the entire supply chain, seeking world-class status for large and small companies alike.

Three trends make the renewed focus on electronics R&D particularly timely. First, the Administration is promoting development of the National Information Infrastructure (NII), which will open new markets for electronic devices. Second, NEMI can exploit the worldwide move from analog to digital technology, in which the United States is the world leader. Third, NEMI can build on the new Federal focus on dual-use technology by strategically aligning funding for electronics R&D to maximize U.S. economic and military competitiveness.

Working together, government and industry, particularly the Semiconductor Industry Association, have developed a technology road map that covers a broad set of component, process, and infrastructure technologies, with a focus on hardware that can connect to the NII. The intent is to develop a strategic approach for setting national priorities in electronics. No new Federal funds are required, only the realignment of the current $1 billion annual investment in electronics manufacturing R&D. The Federal R&D effort builds on and includes ongoing government programs such as those addressing semiconductors, flat panel displays, multichip modules, and environmentally conscious manufacturing. Five Federal agencies are engaged in relevant materials R&D: DOC, DOD, DOE, NASA, and NSF.

The Technical Program

In late 1994 the EMWG held a workshop[12] on electronic materials attended by representatives of industry, academia, and Federal agencies and laboratories. The workshop highlighted the electronics industry's increasing reliance on universities and government for basic research on advanced materials, as private companies have focused more and more on solving near-term practical problems.

In examining the materials needs of the electronics industry, the EMWG workshop focused on the five critical technologies identified in NEMI: microelectronics, radio frequency (RF) and microwave electronics, photonics, mass storage, and module interconnections. The working group also reviewed two generic technology areas important to the application of materials -- materials characterization and materials research. Materials-specific R&D issues were identified for each technology area, as follows.

Microelectronics

Microelectronics R&D is directed generally at increasing processing speed and power, expanding memory and storage capacity, and reducing size and cost. Semiconductors -- the integrated circuits and discrete components that form the core of electronic devices -- generally are made of silicon. Researchers are striving to push silicon to its performance limits, because problems with high-volume processing continue to constrain the use of alternate electronic materials.

Advances in silicon-based technology will require continued developments in sub-micron lithography (small-scale processing of printing circuits); dielectric materials, such as silicon dioxide and polymers, used to separate and insulate devices and prevent crosstalk; and dopant control (the juxtaposition of dissimilar materials in particular locations and concentrations to produce the requisite junctions and device properties). In addition, new and improved processing technology must be developed to enable production of defect-free silicon wafers of increasing size.

[12] A report [17] describing workshop proceedings can be accessed through the World Wide Web (WWW) Server via the Internet using the Home Page electronic address [www.nist.gov] of the NIST/Materials Science and Engineering Laboratory.

RF and Microwave Electronics

In the past, military needs have driven development of RF and microwave electronics, the heart of wireless communications systems. The focus now is on expanding commercial applications, such as cellular telephones, by reducing device size, improving transmission clarity, and increasing power and range.

Specialized electronic materials are used for these types of applications. Gallium arsenide (GaAs), for example, transmits signals more rapidly than does silicon, indium phosphide provides greater signal clarity, and silicon carbide resists damage and high temperatures. However, processing methods uniquely suited to these materials are needed. Currently, fabrication of GaAs-based circuits relies on adaptation of silicon processing technology. Further development of GaAs materials structures also is needed, in order to optimize transistor performance. The overall goal is to develop a large-volume commercial market for RF integrated circuits that is adequate to sustain development of its own infrastructure.

Photonics

Photonic technologies can transmit and modulate information at the speed of light, much faster than electronic devices, and an eightfold increase is projected in the market for opto-electronic equipment over the next 20 years. A leading application is fiber-optic cable, which can transmit much more information than can copper wiring and is increasingly the medium of choice for telephone and cable television systems. Another important application is the flat panel display used in laptop computers. Research is needed to improve the performance and reduce the costs of these technologies. Flat panel displays, for example, are limited in color, size, and visibility from certain directions. They also consume so much power that a computer's battery must be recharged every few hours.

A generic set of materials deposition, processing, and characterization technologies is needed that meets the various requirements for manufacture of photonic components. Each application has unique materials requirements. Continued improvements are needed in indium phosphide, silica glass fiber, and electro-optic materials for telecommunications applications; GaAs and other materials capable of short-wavelength emission, and plastic fiber and related materials for data communications and storage applications; visible-emitter materials for light-emitting diodes (the colors produced depend on the materials used); and large-area liquid crystal display and other advanced technologies for flat panel displays.

Mass Storage

Storage technology is a limiting factor in the evolution of information technologies. Multimedia work stations, for example, will require vast storage capacity for digitized text, images, and sound -- an amount of data that would overwhelm current systems. Materials R&D will help the United States maintain its leadership in this vital field.

Materials advances have the potential to increase significantly the data storage capacity of technologies ranging from hard disk drives to magnetic recording tapes. This research area encompasses many types of materials, including polymers, metals, and magnetic materials. The overall effort is aimed at increasing the reliability, density, processing speed, and ruggedness of devices while reducing their size and cost. Significant challenges must be overcome with regard to design of media and media-access technologies that can exploit the high resolution of high-density memory. Successful use of advanced materials depends on development of a variety of new technologies, such as short-wavelength lasers for use with optical disks, integrated head designs that enable fast access to data, and large-area semiconductor memory.

Modular Interconnects

Advances in packaging, interconnection, and assembly technologies are needed to ensure that overall system performance matches chip-level capabilities. Historically, this type of R&D was conducted by large corporations, but activity levels have declined, and many smaller business with limited research capacities have entered the industry. At the same time, with the increase in Asian production, the U.S. share of the global market in module interconnection has dwindled.

A variety of new and improved materials is needed, such as materials with low dielectric constants for high-frequency applications; moisture-resistant resins; improved solders; conductive adhesives; photo-imageable dielectrics (polymers that can be imaged so the number of lithography steps can be reduced); and fine photoresist materials (dissolvable polymer-type materials used in lithography). In addition, dimensionally stable and improved polymer underfill materials are needed to improve long-term device reliability. The overall objectives are to reduce the costs and enhance the reliability, portability, and performance of modular interconnects.

Materials Characterization

If electronics manufacturers are to develop low-cost, reliable products on a consistent basis, then the application-critical attributes of the materials used to fabricate these products must be measured at all stages. Current techniques enable measurement of materials structures on an atomic scale. However, these methods are not widely used, due in large part to the high cost of state-of-the-art tools and of maintaining in-house quality control. Improved technologies, such as on-line sensors and failure analysis tools, are needed for examining materials during and after processing, and these tools must be made widely available at reasonable cost to users. The EMWG has made a list of 13 materials characterization techniques that need to be developed or improved.

Long-Term Research Opportunities

Research must continue to push the frontiers of materials science and the physics and chemistry of electronic and photonic materials, to support continued development of capabilities to design material and device structures at the atomic and molecular scales. No organization has the financial resources to accomplish this goal alone. It may be possible to develop modeling and simulation tools that reduce the cost of developing atomic-scale devices and fabrication capabilities. In many cases, significant restructuring of the traditional relationships among government, industry, and academia will be required to assure effective direction and coordination of electronics research.

Critical long-term research areas include synthesis, processing, and physical properties of nanostructured materials; computation and simulation of materials properties and processes; heterogeneous and non-lattice-matched growth and epitaxy; interfaces between dissimilar materials; interconnects; nonequilibrium (low-thermal-budget) materials processing; and wide band-gap semiconductors.

Guidance for coupling researchers with manufacturers is likely to be provided largely by technology road-mapping efforts led by industrial associations. The EMWG recommends that the Federal Government encourage private-sector electronic materials R&D by promoting industry-led consortia and creating centers of excellence for collaborative projects, and that a dialogue begin on how industry's technology road maps can provide guidance for Federal R&D while ensuring that breakthrough ideas are recognized and supported.

Evaluation

An evaluation scheme for Federal electronics R&D is being developed. For broad programs such as this, it is not always feasible to set timetables and deliverables at the program level, although milestones can be set for individual projects. One possible approach is to examine milestones achieved over three different time periods:

- short term (2 years): industry participation, as measured by numbers of proposals and extent of cost sharing;
- medium term (5 years): micro outcomes, such as how many funded projects met their goals, and how many and what kinds of jobs resulted from the projects; and
- long term (10 years): broader effects on the economy, in terms of new business creation, numbers and kinds of jobs created, and other measures.

Environmental Materials Technologies

> A new paradigm in the development of environmental materials technologies -- avoidance -- has emerged to take precedence over monitoring and assessment, control, and remediation and restoration.

In two recent reports [18] [19], the NSTC outlined environmental technology strategies aimed at improving and sustaining the environment while at the same time promoting long-term U.S. economic growth. In the vision espoused by the NSTC, reconciling these goals requires an environmental technology strategy that helps industry shift from waste management to pollution prevention, efficient resource use, and industrial ecology. Thus, a new paradigm -- avoidance -- has emerged to take precedence over monitoring and assessment, control, and remediation and restoration.

Maintenance of environmental stewardship and sustainable economic growth within the context of current and future environmental regulations will require the development of technologically sophisticated materials, integrated products, processes, and systems that are designed from the outset to minimize environment impact throughout the entire life cycle. Examples include biodegradable plastics made of starch or other renewable resources; high-temperature ceramic engines and other energy-generation systems that are fuel efficient and non-polluting; and benign chemicals and processes for use in refrigeration, papermaking and printing, furniture coating, industrial degreasing, and de-icing operations.

In the past, materials selection, application, use, and disposition were carried out in a relatively standardized manner with little concern over environmental impacts. Materials industries contribute significantly to wealth creation, but they also are major contributors to the nearly 20 billion tons of waste generated per year in the United States, for which handling and disposition cost billions of dollars per year. Important technologies have been developed for adapting and modifying existing materials processes, but these retrofits rarely represent the lowest-cost solution for compliance with current or future environmental regulations.

The competitiveness of the U.S. economy rests, to a major extent, on the Nation's capability to convert raw materials into useful products that can compete in the global marketplace, while maintaining stewardship of the environment. Several strategies offer significant potential for helping the United States accomplish these goals while reducing costs to industry and society. These strategies include environmentally sound materials selection, development of processes that maximize yield of useful products from raw materials, avoidance of waste generation at the source, and reuse and/or recycling of waste products.

The United States, still rich in many raw materials, faces an ever-increasing challenge in developing improved means for utilization of these resources with minimal environmental impact in a manner that will maintain long-term economic growth. This challenge can best be addressed by collaboration and cooperation among industry, universities, and Federal, state, and local governments, an approach that leverages resources and offers the best chance of achieving broad-based change.

The Technical Program

For the most part, the Federal effort to promote innovation in environmental materials technologies has been integrated into existing programs. Brief summaries of environmentally oriented materials R&D under way at each MatTec agency may be found in Chapter 4 of this report, not only in the sections entitled "Environmental Materials Technologies" but also in descriptions of other programs not labelled as such. The enabling character of materials provides a basis for addressing environmentally sound R&D as sub sets of many product-oriented programs.

At present, however, these activities are neither organized within a government-wide framework nor focused clearly on the new paradigm of pollution avoidance. There remains a need to inventory current and planed Federal programs dealing with environmentally sound materials and processes and to integrate these activities into a coherent whole, with common objectives and plans.

Working Group

In recognition of the need to establish such a framework, an Environmentally Conscious Materials Working Group was established in 1995 under MatTec. The term "environmentally conscious" refers specifically to avoidance technologies. The aim of this working group is to assemble a rational portfolio of environmentally oriented materials R&D spanning the entire materials life cycle (depicted on the front cover of this report), to integrate the Federal agencies into a cooperative application-focused community, and to make this community aware of related industry and university programs as well as foreign technology. The working group also will help this community become informed about and involved in current and pending environmental regulatory matters, which could have considerable impact on the direction and extent of related technical programs.

The ultimate goal of the working group is to develop a road map for integrated government-supported programs on environmentally oriented materials R&D consistent with environmental stewardship and long-term economic growth. This dynamic road map will be developed and periodically updated with the involvement of industrial professional societies and universities and endorsed by the combined Federal community. Because materials and manufacturing technologies are related, interactions with environmentally sound manufacturing R&D programs will help ensure appropriate synergism and minimize duplication.

Working Group Activities

A conference was held in 1993 on Materials and the Global Environment. Sponsored by the American Society for Materials-International and cosponsored by 23 professional societies and associations, the conference was attended by policymakers and representatives from government, industry, and universities, who gathered to discuss issues, summarize current and planned R&D, and formulate strategies to address materials and the environment.

A summary of conference activities is being prepared, along with a compendium of issues, programs, and plans related to environmentally conscious materials development. Based on an evaluation of this summary, a decision will be made regarding the feasibility of holding a workshop in late 1995 or early 1996 to establish a baseline for the road map and identify high-priority technical efforts. Representation from the broad spectrum of organizations involved in the 1993 conference would be involved in the workshop.

Meanwhile, the working group membership will be expanded to include at least one representative from each government agency as well as from other government working groups addressing materials and environmental issues or programs. A summary of all government-supported R&D related to environmentally conscious materials development will be compiled, together with a summary and analysis by the working group, by the end of FY 1996.

Infrastructure Materials Technologies

Most U.S. highways, bridges, and buildings seem to wear out rapidly, and some seem to be in a constant state of disrepair. The effects are highly visible -- and expensive. Highways often are jammed or closed due to a need for perpetual maintenance. Bridges are subject to rapid corrosion, sometimes to the point of collapse. Buildings and other structures can be shattered by earthquakes or other calamities. The Nation's economic vitality and quality of life clearly would be enhanced by expanded development and use of affordable, high-performance materials for durable roads, corrosion-resistant bridges, and strong, flexible buildings, as well as wide use of environmentally sound manufacturing and construction practices.

The extent of the Nation's infrastructural deficiencies, as well as some of the potential benefits of proposed improvements, have been documented many times. For example, some 40 percent of the Nation's 575,000 bridges are structurally deficient or functionally obsolete. Extending the life of 10 percent of bridges with aluminum alloy decks could save more than $100 billion in replacement and maintenance costs.

The infrastructure must be restored, strengthened, and expanded to meet the needs of a growing population and economy while

"Smart" Steel Inspection Technology Improves Bridge Safety

A novel "smart" inspection tool, now undergoing final testing, is expected to enable rapid nondestructive inspection (NDI) of steel bridges, thereby improving both safety and the cost-effectiveness of maintenance programs. The Fatigue Crack Detection System (FCDS) developed by Sierra Matrix of Fremont, California, under contract to DOT's Federal Highway Administration, employs the latest portable computer, voice recording, processing, and display technologies. Traditional ultrasonic testing technology for crack detection is combined with a magnetic field disturbance transducer, which identifies cracks in steel members. The FCDS computer is worn by the bridge inspector as a backpack and powered by a belt-worn battery. A visor worn in front of one eye provides the virtual "heads-up display" of magnetic and ultrasonic data, while the inspector maintains contact with the real environment with the other eye. A single hand-held mouse can be used to interact with a virtual keyboard for data entry. The new tool will help the Nation obtain the best possible performance from aging pavements and bridges. The new tool is among many new NDI methods being developed to monitor the structural integrity and predict the failure of structures, and to assist in the setting of priorities for maintenance and repair. One-third of U.S. bridges are structurally deficient.

improving safety. But U.S. investment in infrastructure relative to the gross domestic product has fallen by almost 50 percent since the 1960s, and the U.S. share of the international construction market has dropped from about 50 percent to 25 percent. This decline has weakened overall U.S. industrial productivity, because building and construction (including renovation) is a huge, $800 billion industry employing some 10 million workers.

Part of the problem is low U.S. investment in construction-related R&D, much of which involves materials. Private-sector investment is limited by the fragmented nature of the construction industry and the small size of most firms. A number of studies and surveys have indicated that the United States is falling behind foreign competitors in many areas of construction technology, including materials innovation.

To improve both the condition of the infrastructure and prospects for the construction and building industry, a Federal R&D effort is under way on two fronts[13]. First, an initiative launched under the CCIT Subcommittee on Construction and Building (C&B) is aimed at improving the performance of buildings throughout their life cycles. The objectives are to help remove non-technical barriers to innovation, increase the emphasis on R&D, and align government programs appropriately with industry needs. The initiative responds to a high level of industry interest and combines the goals of both government and industry. Research is conducted in cooperation with industry, labor, and academia.

On a second front, a materials R&D effort led by industry seeks to address both C&B objectives and transportation infrastructure needs. Working with C&B, the Civil Engineering Research Foundation brought together experts from industry, government, and academia to develop the 10-year High-Performance Construction Materials and Systems Program (CONMAT). The goal of CONMAT is to help create the materials and systems for an entirely new generation of constructed facilities. Approximately one-third of the proposed program would be devoted to transportation-related R&D, while most of the remainder falls in the C&B focus areas.

After examining research needs identified by industry, the C&B defined two priority thrusts for its initiative: (1) improved construction through 50 percent reductions in the time lag between project conception and readiness for

[13] Additional information may be found in various reports [20,21,22,23,24].

service, operation and maintenance costs, occupant-related illnesses and injuries, and construction-related waste and pollution; a 30 percent increase in occupant productivity and comfort; and a 50 percent increase in structure durability and flexibility of use; and (2) improved health and safety of the construction work force through a 50 percent reduction in illnesses and injuries (the construction industry employs only 6 percent of the U.S. work force but pays about one-third of the Nation's workers' compensation).

High-performance infrastructure materials, components, and systems constitute one of seven categories of technologies identified as essential to the achievement of C&B goals. Development and improvement of these technologies is expected to hasten delivery of facilities and improve durability and reduce waste and pollution. CONMAT is designed to achieve the performance improvements set forth by C&B by accelerating the commercial use of high-performance construction materials and systems.

The Technical Program

Research on high-performance materials, such as concrete and steel, has been under way for many years in various Federal agencies. High-strength concrete has been developed, for example, although it represents only 5 to 10 percent of the concrete placed annually in the United States. However, past R&D activities have been inadequate in terms of their ability to address comprehensive, long-term problems; instead, they have been designed to fit available funding and meet immediate operational needs. Few projects have been devoted to building and testing prototype structures or systems, or to analyzing a structure from materials selection to final concept testing.

The C&B initiative takes a broad, systems-oriented perspective that addresses both short- and long-term issues. The initiative has been integrated with ongoing Federal R&D and will help accelerate work in several important areas, such as incorporation of advanced materials into highway design, and final development of nondestructive evaluation (NDE) and robotics inspection techniques for bridges. CONMAT encompasses 10 construction materials groups, including both high-performance traditional and advanced materials.

Seven Federal agencies are involved in infrastructure materials R&D. The USDA concentrates on high-performance wood products and systems. The DOC program addresses high-performance concrete, steel, and composites. Two agencies, DOD and DOI, focus on both concrete and steel, while DOE concentrates on steel. Two agencies maintain multifaceted programs: NSF, which addresses concrete, steel, composites, polymers, and "intelligent" materials; and DOT, which works with many materials, including concrete, geotextiles (permeable synthetic textile products), asphalt, steel, and composites.

Materials of Interest and Research Issues

Concrete, which is easy to form and has high compressive strength, is the most extensively used construction material, but many factors affecting its performance are poorly understood. The knowledge base must be expanded if higher strengths and other superior properties, such as high durability and ductility, are to be developed. Issues requiring attention include process control to ensure consistent high performance, design of structural members to prevent buckling and assure impact resistance, development of procedures for determining where steel and concrete can be used together to optimize a structure, and long-term performance of concrete structures.

The key CONMAT objectives for concrete are in-place quality improvements and optimized design for durability and strength enhancement. Federal concrete R&D includes development of methodologies to predict performance, especially service life; research on seismic design and performance; in-situ monitoring of structures; development of nondestructive test methods; computer simulation of material properties; and development of expert systems for analyzing pavement materials.

Steel, due to its ductility and high tensile strength, is the other most commonly used infrastructure material. The construction industry uses about 20 million metric tons of steel annually, but in a wide variety of different types of steel and product shapes. The diffuse nature of this market has not drawn significant

R&D attention to structural steel in recent years. Yet there is a need for structural steels of improved quality and performance to increase the flaw tolerance, efficiency, and lifetime of structures. There is also a need for advanced steelmaking techniques that minimize waste and pollution.

CONMAT objectives for steel are to enhance capabilities to predict material performance and to improve overall life-cycle performance. Federal steel-related R&D focuses on processing technology, welding, fracture mechanics, failure analysis, corrosion, and NDE.

Composites, which have a high strength-to-weight ratio and resist corrosion, are a CONMAT research priority. The objective is to create a new generation of composite bridge, marine, and utility structures with reduced life-cycle costs and construction times. Examples of composite structural materials are concrete containing metal fibers that enhance energy absorption capacity; and polymer-matrix materials, which can be used to make large, complex structural parts that are highly reliable and require little maintenance.

Following is a summary of other infrastructure materials and key CONMAT objectives:

- *Aluminum* resists corrosion and has been used successfully in some bridges, but it costs more than steel. The CONMAT objective is optimization of aluminum alloys and structural systems to emonstrate competitive life-cycle costs for bridges and structures for severe environments.
- *Hot mix asphalt*, composed of asphalt cement and mineral aggregates, is a common pavement material with several flaws, including cracking in cold weather, instability in hot weather, and oxidative hardening with age. The CONMAT objective is to improve in-place quality and life and to reduce waste and pollution.
- *Coatings* (such as paint) protect steel from corrosion but in their present forms are often hazardous to the environment. The objectives are to enhance environmental compatibility and reduce overall life-cycle costs of coated structures. Metallic coatings such as zinc, for example, show potential for increased long-term durability and minimal emissions.
- *"Smart" materials* contain sensors that can diagnose internal structural problems, such as corrosion and fatigue, or provide heating and other desirable features. The objective is continued development of reliable communications and sensor technology, focusing on reductions in life-cycle cost.
- *Wood* is a durable, renewable, and recyclable resource used in light building construction and rural or temporary bridges. The objective is development of new, low-cost forms of wood with enhanced durability and strength. Examples include wood products that resist fire and decay.
- *Roofing materials* include thermal insulation, waterproofing membranes, mechanical fasteners or adhesives, and surfacing. High-performance roofing materials are those with improved wind and fire resistance and energy efficiency, longer service life, and reduced life-cycle costs. The objective is extended service life and energy conservation,
- *Masonry* (such as brick) has a compressive strength similar to that of concrete but has not been exploited fully as a structural material. The objective is enhanced construction quality and reduction in risks related to natural hazards.
- Other construction materials such as gypsum, geo-fabrics, glass, and plastic will be included in the R&D effort as partnerships with industry are developed.

Evaluation

The baseline for measuring progress toward the C&B goals is today's current construction practices. All interested groups from industry and the public sector will be involved in evaluating the initiative's progress. An evaluation plan has yet to be developed.

4. Agency Materials R&D Programs

Department of Commerce

DOC Primary Organizational Units Sponsoring R&D Programs in Materials Science and Technology:

National Institute of Standards and Technology (NIST)

- Materials Science and Engineering Laboratory (MSEL)
- Electronics and Electrical Engineering Laboratory (EEEL)
- Chemical Science and Technology Laboratory (CSTL)
- Building and Fire Research Laboratory (BFRL)
- Physics Laboratory (PL)
- Computing and Applied Mathematics Laboratory (CAML)
- Technology Services (TS)
- Advanced Technology Program (ATP)

Overview of Materials R&D Activities

The broad mandate of the Department of Commerce (DOC) is to ensure and enhance long-term economic opportunity and a rising standard of living for all Americans by working with the private sector. The DOC's National Institute of Standards and Technology (NIST) plays a leading role in Federal efforts to improve the use of technology in the competition for global markets. Its mission is to promote economic growth by working with industry to develop and apply technology, measurements, and standards.

NIST is organized into 10 operational units, including eight laboratories; Technology Services (TS), which along with the Office of the NIST Director is largely responsible for management of NIST's extramural programs; and an administrative support unit. One laboratory, the Materials Science and Engineering Laboratory (MSEL), is devoted entirely to materials R&D, and its director chairs MatTec. Technology Services conducts and supports materials R&D in reference materials and data, calibration services, and technology outreach efforts.

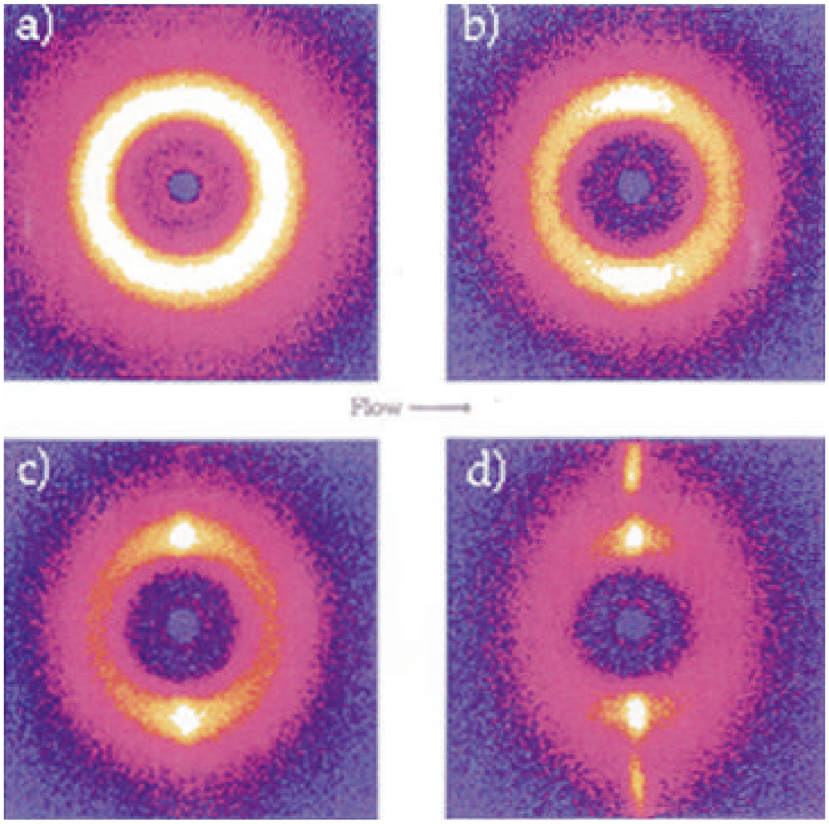
MSEL is the central Federal resource supporting technology development in advanced materials and advanced processing of materials for application in the civilian economy. The MSEL carries out about 80 percent of NIST materials R&D. Also active in this arena are the Electronics and Electrical Engineering Laboratory (EEEL), the Chemical Science and Technology Laboratory (CSTL), Building and Fire Research Laboratory (BFRL), Physics Laboratory (PL), and Computing and Applied Mathematics Laboratory (CAML).

The guiding values of MSEL are the quest for technical excellence, involvement of industry in all aspects of the laboratory's work, and service as an objective source of reliable technical knowledge. The laboratory's objectives are to foster the use of advanced materials in commercial products, foster the development and implementation of technologies for advanced processing of materials, and support the measurement base and standards for materials science to serve the needs of U.S. industry.

MSEL has five technical divisions, including the three material-specific divisions of Ceramics, Metallurgy, and Polymers, the interdisciplinary Materials Reliability Division, and the Reactor Radiation Division. MSEL also has an independent program office, Intelligent Processing of Materials. Each unit fosters the economical processing and safe and efficient use of materials and products by improving materials quality, manufacturability, and reliability.

NIST Expertise Helps Company Solve Glass Fracture Mystery

NIST's expertise in fracture mechanics helped a major high-technology company resolve a mysterious problem in a new product and thereby retain its presence in a market dominated by foreign firms. Hewlett-Packard Co., the only U.S. maker of scanners, had introduced a remarkably affordable color model, which converts text and images into a digital format. A problem developed, however, when some users reported diagonal cracking in the copyboard glass, on which the material to be scanned is placed. The company initially suspected shipping problems but found that the glass was difficult to break, even when dropped. Eventually, with the assistance of NIST's Materials Reliability Division, the company found that the plastic cover, which secures the glass in the machine, had introduced damaging levels of stress into the corners of the glass, setting the stage for what engineers refer to as static fatigue. Access to NIST experts saved an estimated four months of time and associated expenses for the company, which, by redesigning the scanner cover, was able to solve the problem quickly and inexpensively.



Stringent requirements for new applications using polymer blends/alloys, together with the complex nature of polymer processing, have made it necessary to develop a more scientifically disciplined approach to process design and control. Techniques such as small-angle neutron scattering (SANS) are being used to characterize and model the effects of processing shear forces on development of the blend grain structure. The SANS pattern shifts (a-d) from an isotropic ring pattern to an anisotropic spot pattern. This corresponds to a shear rate increasing from zero and reveals the structure evolution from a random grain structure (a), through a structure with a single predominant grain alignment (c), to a highly aligned grain structure of two dominant grain orientations (d).

The Ceramics Division focuses on advanced ceramics and advanced processing of ceramics, for both structural applications, such as automotive engine components, and functional applications, such as optical and electronic devices. Areas of emphasis include processing science, powder characterization, development of test methodologies and models, and state-of-the-art microstructural characterization techniques.

The Metallurgy Division concentrates on materials processing, especially process control based on sensing and modeling, while also maintaining strong programs in materials characterization and data and standards. Processing programs are grouped into four broad areas: liquid-solid metal processing, such as powder atomization and casting; electroforming; thin-film vapor deposition; and processing of strip steel.

The Polymers Division provides standards, measurement methods, and fundamental concepts of polymer science to assist industries that produce or use polymers, polymer blends, and polymer-matrix composites. Topics are identified at NIST workshops involving industry. Current topics of interest include characterization of polymers used in electronic applications, such as electronic packaging; and development of new and improved dental materials.

The Materials Reliability Division fosters the increased use of advanced materials in commercial products, through research aimed at improving confidence in their service performance. The division focuses on three research themes: "intelligent" processing of materials (IPM), ultrasonic (i.e., nondestructive) characterization of materials properties, and micromechanical measurements.

The Reactor Radiation Division operates the thermal neutron research reactor and the Cold Neutron Research Facility, a National User Facility offering unique capabilities using thermal and cold neutron scattering techniques for materials science, condensed matter physics, and chemistry. The division develops and maintains state-of-the-art instrumentation for materials research, nondestructive evaluation (NDE), chemical analysis, neutron standards, dosimetry, radiation metrology, and isotope production.

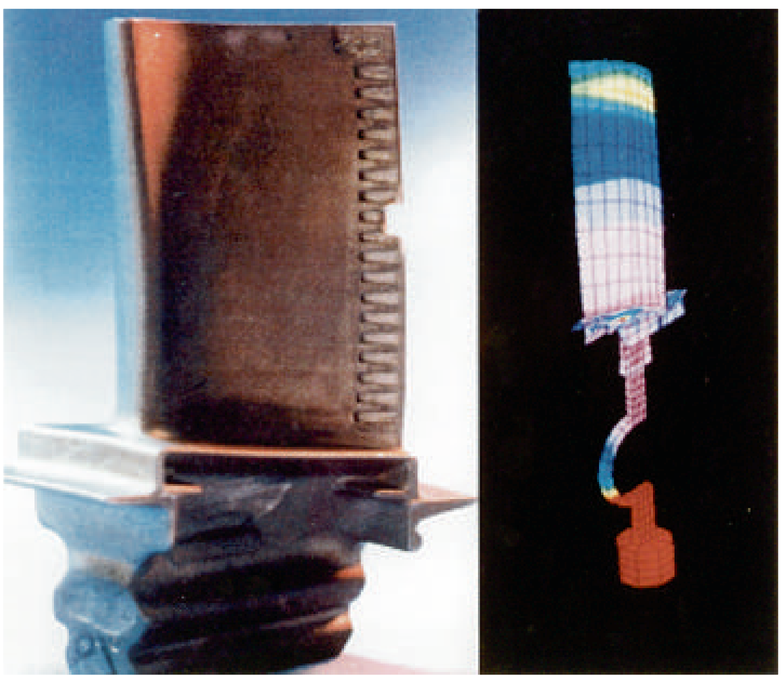
The Office of Intelligent Processing of Materials sponsors cross-cutting interdisciplinary research throughout NIST, focusing primarily on IPM and NDE. Related activities include development and application of on-line sensors for manufacturing, process models that link process variables with the desired microstructure, and related computer and control systems. The office also manages the Center for Theoretical and Computational Materials Sciences, a distributed (or virtual) center that develops materials theory and applies it to practical problems.

Materials R&D Related to National Priorities

Aeronautical Materials Technologies

Because affordability is a key driver of competitiveness in the aerospace industry, NIST's expertise and established programs in IPM will be critical to development of the next generation of aircraft. NIST also addresses a number of other relevant topics, including development of low-cost, lightweight materials for use in subsonic airframes; lightweight, high-temperature materials for use in turbine engines and supersonic airframes; and low-cost, environmentally friendly materials processes.

Specific NIST efforts in aeronautics include a program dedicated to development of advanced composites for use in aircraft fuselages, and the Aerospace Alloy Casting Consortium, a joint effort with industry. NIST research projects under the consortium include development of process models and sensors, and measurement of materials properties.



Metal castings for use in aerospace applications must meet stringent quality requirements and must be produced on schedule and at competitive cots. Traditional design casting processes, which can involve processing multiple test castings and evaluating their microstructure, can be costly and require months of effort. Modeling and simulation techniques can be used to make test castings on a computer and evaluate the results of predictive models for microstructure and defect formation. This approach can reduce significantly the time required to develop an acceptable casting design and reduce the number of costly prototype test castings. The photograph shows a turbine blade from a high performance aircraft engine (left), and a computer simulation of the thermal field during solidification of a single-crystal turbine blade (right).

Automotive Materials Technologies

Along with four other Federal agencies, NIST is a key player in the Partnership for a New Generation of Vehicles (PNGV). NIST research areas relevant to the PNGV include advanced materials, new manufacturing processes, high-performance computing and communications, advanced electronics and controls, environmental technologies, and measurement standards and techniques. NIST also has several major programs designed to spur industrial innovations, accelerate the use of new technologies, and encourage industry to improve quality.

More specifically, a number of NIST programs focus on development of the lightweight, cost-effective, recyclable materials needed to reduce vehicle fuel consumption and reduce emissions. Such materials include aluminum, ceramics, intermetallics, polymers, and composites. NIST also addresses development of high-strength, high-temperature-tolerant materials, such as ceramics and metal-matrix composites, for advanced engine components. Programs in "intelligent" processing and agile manufacturing support the effort to improve the productivity of the auto industry. In addition, focus areas in the Advanced Technology Program (ATP) include motor vehicle manufacturing technology and manufacturing of polymer-matrix composites for structural applications, such as automobiles.

Electronic Materials Technologies

NIST carries out numerous programs related to materials for electronics applications. In one joint effort launched recently, NIST and DOE are coordinating their R&D projects and assigning researchers to address priority technology needs and issues identified by the Semiconductor Industry Association (SIA).

NIST established the National Semiconductor Metrology Program, which involves some materials R&D, in response to the technology road map developed by SIA.

Packaging materials and processing technologies are a key focus of NIST electronics R&D programs. Fabrication of complex, advanced microcircuits on a commercial scale will require significant improvements in manufacturing processes, in part because of critical problems in packaging or connecting these devices with other system components. MSEL is developing the measurement tools necessary to define realistic electrical, mechanical, thermal, and chemical properties of materials used in packaging and interconnections.

Environmental Materials Technologies

NIST programs address a key challenge identified in the Federal environmental technology strategy -- materials for industrial ecology. The goal is to develop an industrial system of material use that is compatible with environmental constraints. Research addresses alternative processing methods and advanced materials that reduce waste production, minimize resource use and pollution, and improve energy efficiency. In the processing area, NIST is developing methods for making polymers from recycled materials, and the Manufacturing Extension Partnership (MEP) promotes environmentally sound manufacturing. NIST materials research focuses on environmentally benign chemicals for use in printing, manufacturing, and metal plating and coating.

In addition, as part of the overall Federal effort to improve air quality, NIST has developed software to help evaluate alternative refrigerants that can replace ozone-depleting compounds, such as chlorofluorocarbons. The ATP also involves related efforts. One 1995 ATP focus area is advanced vapor compression refrigeration systems; the goal is to develop efficient, quiet, and compact systems with minimal environmental impact.

Infrastructure Materials Technologies

As part of the national effort to improve the building and transportation infrastructure, NIST conducts R&D addressing risk reduction technology, environmental quality, performance standards, and automation in design. NIST also is expanding its programs in high-performance materials components and systems, in an effort to improve structural durability, reduce waste and pollution, and speed up delivery of facilities.

NIST is leading the planning of a nationally coordinated research program on high-performance concrete. NIST research in this area focuses on development of methodologies to predict performance, especially service life. Steel-related research focuses on processing technology, fracture mechanics, failure analysis, and NDE. Another important effort involves the development of performance-based codes and a national system for the acceptance and approval of innovative products.

Interaction with the Private Sector

Collaboration with industry is a tradition at NIST. Recently, this emphasis has become even more pronounced, and there has been increasing collaboration with materials utilization companies -- the applications-oriented segment of the industrial community. The NIST R&D program involves joint technology development with both materials producers and materials users. NIST also provides industry with standard reference data in order to improve manufacturing processes and products. Since 1982, more than 46,000 units of standard reference materials have been sold, with a value in excess of $8 million.

MSEL cooperates closely with industry and other NIST laboratories in identifying national trends in materials research. Industry participates in both planning and execution of collaborative research to address critical problems in materials technology. Various criteria are used to identify technologies and industrial sectors where MSEL programs can have a major impact; focus areas must have national significance for civilian technology, and the projected research results must have the potential to help improve industrial competitiveness.

NIST recently launched three consortia in the areas of aerospace alloys, advanced processing of polymer blends, and advanced biosensors (electronic devices employing biological molecules as sensors). Twenty-eight firms are participating in these consortia. An earlier NIST-industry consortium focusing on metal powder research produced major technical advances in the areas of atomization process modeling through computational fluid dynamics, real-time particle size sensing, and "intelligent" control. This success led to the formation of a follow-on consortium with the objective of robust demonstration of powder particle size control through IPM.

In addition to joint research with industry, NIST also employs a network of delivery systems to transfer to the private sector an array of scientific knowledge, predictive models, measurement methods, reference data and materials, and standards. Delivery mechanisms include published papers and reports, invited lectures, workshops and symposia, patents, professional societies, national and international standards organizations, and trade associations.

MSEL has implemented a multi-faceted approach to enhance technology transfer. In 1992, for example, MSEL sponsored or co-sponsored with industry two dozen workshops on topics of strong industrial interest, and almost 320 U.S. scientists, 40 percent from industry, visited MSEL to work with the staff on problems of mutual concern. These researchers are able to transfer the results of the collaborations to their own organizations. In addition, since 1986 MSEL has entered into more than 100 Cooperative Research and Development Agreements with 76 different organizations, including 59 companies, trade associations, and industrial consortia.

A number of unique programs involving industry have been established at NIST in recent years. Much of the work carried out through these programs involves materials-related R&D. The best-known effort is the ATP, which, through a competitive proposal process in both general and focused technology areas, provides funding for cost-shared R&D projects conducted by industry. The goal is to assist in the development of high-risk technologies that have major commercial applications but remain at a precompetitive stage. Many projects involve materials R&D. Fifteen current projects focus on manufacturing of polymer-matrix composites for large, commercial structural applications, such as automobiles and bridges. New focus areas for 1995 include materials processing for heavy industry.

Also based at NIST is the MEP, which through community outreach centers and other services assists the Nation's 350,000 small and medium-sized manufacturers in modernizing production capabilities and addressing other needs. These firms employ some 6 million Americans and supply vital components for the manufacture of high-value-added products ranging from computers to automobiles. Some MEP clients and activities address materials-related issues. The goal is to establish an integrated, nationwide network of 100 outreach centers that can provide seamless, coordinated technical and business support services.

NIST also:

- participates in the government-wide Small Business Innovation Research program, in which small companies compete for awards to commercialize the results of Federally supported research, including materials-related work;
- works with DOE on the Energy Related Inventions Program, which offers one-time support for development and commercialization of energy-related inventions, including materials; and
- collaborates with five other agencies in the Technology Reinvestment Project, which solicits a variety of R&D projects, including materials-related projects, to promote development of new technologies for civil and military use.

Materials R&D Base Programs

Materials Science and Engineering Laboratory

To maintain its leadership role in materials science and technology research and its ability to respond to national priorities and needs, MSEL has developed a plan to (1) extend traditional strengths in structural materials to encompass advanced materials; (2) expand programs in materials processing, including sensor development and process modeling; (3) broaden the focus on materials utilized for their electronic, optical, and magnetic properties in information and communications applications; and (4) increase interaction with industry in areas of high mutual priority, through joint technology development.

Recent program developments have focused on broad categories of advanced materials, particularly advanced ceramics and high-performance polymer-matrix composites; advanced processing of materials; and materials characterization. Looking forward, the five-year technical plan calls for narrowing in on new, interdisciplinary topics with high potential for significant impact. These topics include materials theory, modeling, and computation; coatings and interfaces; metal-matrix composites; magnetic materials; photonic materials; nanostructured materials; and precision machining of advanced materials.

Materials Theory, Modeling, and Computation

New theoretical and computational approaches are augmenting and often replacing the expensive and time-consuming search-and-test methods traditionally used to develop new materials and associated manufacturing processes. Advances in computer processing power and computational methodologies are spawning a new field of materials research, computational materials theory.

Progress in this field is rapid but disorganized and could benefit from development of a distributed (or virtual) center that would extend and improve interactions among researchers. NIST is planning such a center of excellence, which would form temporary, cross-disciplinary research teams linked electronically to address key materials issues. The principal activities would be planning, research, and technology transfer.

Coatings and Interfaces

Ceramic, metallic, and organic coatings are used on all classes of structural substrates to improve corrosion and wear resistance, reduce substrate temperature, and control friction. Layered coatings are used on both current and emerging technologies.

Layered ceramic coatings have been deposited successfully under some conditions, especially those involving structural applications, but there are no standardized techniques for measuring properties such as strength, modulus, delamination, and subsurface defects, and there are no models for predicting performance based on microstructure. MSEL is developing measurement and analysis techniques that would provide for improved reproducibility in the processing of layered ceramic coatings.

Metal-Matrix Composites

Lightweight-but-strong composite materials have been developed for defense applications but at present are far too expensive for most commercial applications. However, metals producers have begun to introduce lower-cost metal-matrix composites (MMCs) based on alloys of aluminum and, for the future, magnesium. Initial applications include automotive components.

Technical barriers to wider use of MMCs include the absence of both fundamental understanding of their behavior and a reliable database of mechanical properties. MSEL seeks to improve materials performance by identifying new reinforcing fiber materials, controlling interface reactivity, and working with industry to incorporate a predictive capability into the evolving database for materials designers.

Magnetic Materials

Dramatic advances are being made in magnetic materials for many high-technology applications, such as magnetic recording and information storage, and electric power generation, transmission, and distribution systems. The trend is toward use of thin films. Processes must be developed to fabricate and characterize layered films with the requisite magnetic and structural properties on the nanoscale, and methods and standards must be developed to assure quality control during manufacturing. MSEL has planned an extensive, long-term program in research and method development focusing on new magnetic and superconducting materials and thin films.

Nanoscale Magnetic Materials Enable Advances in Copiers

Novel composite materials with very high magnetic strength, engineered by Xerox Corp. with the assistance of NIST's Materials Science and Engineering Laboratory (MSEL), hold great promise for use as advanced toners for color copiers and printers. In conventional copiers, resolution has been improved through the use of magnetic fields to assist toner transport. However, ordinary toners incorporating a magnetic species are optically opaque and therefore useful only for black-and-white reproduction. The new material's unusual properties are due to nanometer-sized magnetic particles, which are embedded in a polymer matrix through an ion-exchange process. In addition to possessing high magnetic strength which enhances resolution, the composites are partially transparent to visible light, making them suitable for color reproduction. MSEL scientists demonstrated appropriate processing techniques and characterized and measured samples, thereby helping Xerox engineer nanocomposites with more than five times the magnetic strength of previous generations of these materials. The new materials are so promising that a pilot plant has been established for commercial production.

Photonic Materials

Optical technology promises dramatic improvements in telecommunications, information technologies, and consumer products such as high-definition television. Future advances in this field are likely to depend on improvements in devices for signal modulations and switching, where the issues are materials based rather than systems related.

Progress in this area depends on the development of economical methods for producing optical-quality thin films, as well as increased understanding of interface reactions between substrates and optical films, degradation mechanisms in optical films, and the control of optical properties under in-service conditions. MSEL has undertaken pilot efforts focusing on topics such as development of magneto-optics from nanocomposite materials, and optical thin films based on polymer liquid crystals.

Nanostructured Materials

Materials composed of nanometer-scale phases represent a new class of materials with a broad range of potential applications. These materials, which can be metals, ceramics, polymers, or various combinations thereof, can possess unusual and useful mechanical, electrical, optical, and magnetic properties.

To assist in successful commercialization of nanostructured materials, MSEL plans a three-phase program that includes (1) development of a fundamental understanding of material property changes resulting from nanometer-sized phases; (2) in-depth study of four parallel synthesis techniques, including chemical synthesis, mechanical attrition, vapor condensation, and electrodeposition; and, (3) in collaboration with the CSTL, identification of key application areas and establishment of interactions with potential industry partners for future development of pilot-scale operations.

Precision Machining of Advanced Materials

The properties that make advanced materials attractive also can make them difficult and expensive to machine. Thus, the high performance of ceramic automobile components, such as bearings, valves, turbine rotors, and fuel injector components, depends in part on the development of advanced precision machining techniques. In collaboration with industry and other NIST divisions, MSEL is developing innovative machining procedures and techniques for quality assessment and process optimization.

Electronics and Electrical Engineering Laboratory

EEEL provides generic measurement capabilities in the interrelated areas of electronics, opto-electronics, electromagnetics, cryoelectronics, and electrical engineering. Materials R&D efforts, conducted in each of five EEEL divisions, concentrate on several broad areas, including semiconductor materials, both silicon and compound; magnetic materials; both high- and low-temperature superconductors, including cryo-electronic devices and metrology; electromagnetic properties of materials at microwave and millimeter-wave frequencies; and physics of opto-electronic structures.

Improved computer algorithms for microwave measurement of materials properties, including scattering and dielectric behavior, have been developed as part of a program in electromagnetic characterization of materials. Recently, new capabilities have been developed for surface resistivity measurements at cryogenic temperatures and microwave frequencies. Property measurements are carried out on systems, components, and materials that generate, guide, and control electromagnetic fields in applications such as interconnects, filters, antennas, and monolithic integrated circuits.

Within the programs on opto-electronics, magnetics, and superconductors, EEEL has developed in-house thin-film production capabilities, including a chemical-beam epitaxy system for fabricating high-quality waveguides and devices and superconducting films. A laser ablation/deposition system is also in use. For characterization of magnetic and bulk superconductors, a variety of scanned-probe microscopy technologies are being pursued, including magnetic-force and NIST-developed tunneling-stabilized magnetic force microscopes. A new optical microscope that reveals property-related material structures (as opposed to physical or magnetic domains) is also under development. One area of focus is fine-detail structures in magnetic recording thin-film media and thin-film heads.

For semiconductor materials, high-accuracy measurement methods are being developed for characterizing properties such as dopant levels, defects, and impurities in silicon, germanium, and oxide films. Specifically, dopant density is determined by two-dimensional mapping of resistivity striations, ellipsometric methods are used to determine film thicknesses, and X-rays and Raman scattering are used to develop data for modeling of crystal structure, chemical bonding, and lattice dynamics in silicon-germanium alloys. An optical characterization laboratory has been established. A molecular-beam epitaxy system is available for fabrication of a variety of structures, including vertical-cavity surface-emitting lasers and standard specimens for quantum Hall resistance measurements.

Chemical Science and Technology Laboratory

CSTL's mission is to develop the national system of chemical measurement through basic and applied research in analytical chemistry, biotechnology, chemical engineering, and physical chemistry. Specifically, CSTL studies the phenomena on which measurement of composition and behavior of chemical and biochemical systems is based; acquires and disseminates thermophysical, thermodynamic, kinetic, and thermal data; and develops new laboratory and process measurement techniques.

Current materials R&D activities focus on materials data, characterization, and processing. In the data program, thermophysical properties, including conductivity and expansion, are determined in various temperature regimes on materials such as advanced polymer and ceramic-matrix composites for applications in aerospace, materials fabrication, energy, and transportation. Thermodynamic data on electronic and other technologically important materials, including germanium and silicon compounds, are measured and used to deduce fundamental properties such as bond energies.

Microanalysis techniques are being developed for chemical, morphological, and crystallographic characterization of materials from the micrometer to nanometer scales. Composition mapping, including three-dimensional depth profiling, is used to measure diffusion zones at interfaces, in metal alloys, glass-metal boundaries, and high-temperature superconductors.

Building and Fire Research Laboratory

The major goals of BFRL are to improve the productivity of the U.S. construction industry and to reduce the human and economic losses resulting from fire, earthquakes, winds, and other hazards. Through performance prediction, improved measurement technologies, and other technical advances, BFRL works to improve the overall quality of constructed facilities throughout their life-cycles.

Four of the five BFRL divisions are involved in development of methods for predicting and measuring the performance of building materials. Related materials R&D programs focus on providing the technical basis for generic and material-specific standards for structural, thermal, fire, and service life aspects of high-performance construction materials, including concrete, steel, composites, coatings, and roofing materials. Current R&D programs address methods for predicting the performance and service life of building materials based on measurements of their chemical, physical, and microstructural characteristics as well as their service environments.

Physics Laboratory

PL conducts research on the physics of materials in the course of providing measurement services and other support for the development of electronic and magnetic devices, optical technology, and radiation applications and control.

Materials research areas with electronic applications include magnetic microscopy, direct-write lithography, extreme ultraviolet projection lithography, and diagnostics for process control in semiconductor production.

Materials research areas with optical technology applications include materials characterization for advanced optical devices; and thermal imaging, sources, detectors, and systems for process control. Radiation facilities are used to measure the properties of materials, such as high-temperature superconductors and thin-film devices, for these applications.

Materials research areas with ionizing radiation applications include advanced techniques in materials dosimetry for identifying embrittlement in reactor materials; development of dosimeter films for industrial, materials-testing, medical, and agricultural applications; application of thin-film dosimetry for quality control of the curing of thin films, coatings, and laminates; and development of novel radiation sensors with wide dynamic response range, ruggedness for industrial applications, and the capability to measure radiation dose distributions with high spatial resolution.

Computing and Applied Mathematics Laboratory

In support of a broad spectrum of NIST materials programs, CAML provides expertise in mathematical modeling, algorithm and software development, statistical design and analysis, and graphics, all in collaboration with researchers at MSEL, BFRL, and other NIST laboratories.

Current collaborative programs focus on static and time-dependent modeling of two- and three-dimensional thin magnetic films; modeling of acoustic emissions in metal plates; modeling of fracture and elasticity of composite materials; determination of solid-liquid interface energies; transport of heat and material during processing; interface stability during solidification; optimized measurement of cement strength using response surface methodology; multivariant modeling of cement and concrete behavior and analysis of sensor data for crack detection in structures; development of a measurement method for thermal expansion of polymer films using experimental design; and generation of reference data for ceramics grinding processes from inter-laboratory studies.

Technology Services

TS manages NIST's extramural technology services, including the development, production, and distribution of Standard Reference Materials (SRMs) and Standard Reference Data.

The Standard Reference Materials Program distributes more than 1,300 SRMs developed and certified in seven NIST laboratories. The customer base for these materials is over 60,000, of which 25 percent are in foreign countries. Customers use SRMs to achieve conformance with process requirements and measurement quality that address international as well as national needs. SRMs are certified for specific properties and issued with legal certificates containing the results and associated uncertainties. SRMs are divided into three categories: chemical composition, physical properties, and engineering.

The Standard Reference Data Office develops and disseminates publications and databases of critically evaluated physical, chemical, and materials properties of substances. Data programs are carried out in 22 data centers and approximately 20 short-term projects located in the technical NIST laboratories and academic and industrial laboratories.

Activities are aggregated into five discipline-oriented program areas: chemistry data, physics data, materials property data, building and fire research data, and data supporting computer software development. The materials property data effort focuses on five topics: structure and characterization, physical properties, phase equilibria, performance properties, and computer access issues. Seven ongoing data centers have been established: Crystal Data, Structural Ceramics, Phase Diagrams for Ceramists, Corrosion, Ceramics Machining, Superconductivity, and Composites Permeability. Each has cooperative agreements linking its activities to outside technical groups, including professional societies and research institutions.

Major Laboratories and Centers of Excellence

NIST has some of the premier research and testing facilities in the United States, including a number of laboratories unequaled in the world. Many of these are available to independent researchers, business, industry, and academia on either a collaborative or an independent (proprietary) basis. Complementing this array of facilities is a broad range of scientific and engineering expertise, also available to assist outside researchers.

The unique or specialized facilities and measurement systems available within MSEL host the full spectrum of materials research activities, including projects in fundamental properties, processing, characterization, and performance. Facilities include: NIST Supersonic Inert Gas Metal Atomization Facility, Acoustic Microscope, Laser Vapor Mass Spectrometry, Powder Characterization Laboratory, Surface Forces Laboratory, Tribology Laboratory, Ceramics Creep Laboratory, Million-Pound-Force Machine for Cryogenic Testing, Thermomechanical Process Simulator, X-Ray Laminography Facility, Dielectric Spectrometry, and Forced Rayleigh Scattering Facility.

Additional MSEL facilities available for proprietary research as well as collaborative research include the National User Facilities, described elsewhere in this report; Small-Angle X-Ray Scattering System; Thermal Pulse Charge Distribution in Polymers; and Gas Permeation in Polymers.

Many other, smaller NIST facilities also are available for materials research. The Synchrotron Ultraviolet Radiation Facility (SURF) provides an intense source of radiation from the infrared through the soft X-ray regions. The SURF is used to measure properties of high-temperature superconducting materials and thin-film devices, and to develop new techniques, such as infrared and X-ray microscopy, for materials research.

The recently completed Medical Industrial Radiation Facility provides materials research opportunities in the medical, industrial, and environmental fields.

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National User Facilities

Contacts for National User Facilities are listed in Chapter 4, National User Facilities.

Annual Reports are available by contacting:

Report Title: Annual Report, Materials Science and Engineering Laboratory (MSEL); and MSEL division annual reports

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Department of Defense

DOD Primary Organizational Units Sponsoring R&D Programs in Materials Science and Technology:

The Army

Army Research Office (ARO)
Army Research Laboratory (ARL) Directorate
Research, Development and
Engineering (RD&E) Commands

The Navy

Office of Naval Research (ONR)

The Air Force

Air Force Office of Scientific Research (AFOSR)
Wright Laboratory Materials Directorate

Advanced Research Projects Agency (ARPA)

(Includes Technology Reinvestment Program)

Overview of Materials R&D Activities

Department of Defense (DOD) materials R&D is fundamental to enabling or supporting technology for every system that flies, navigates on land or water or under the water, or shoots or is shot at, as well as for the general infrastructure of surveillance, command, control, communications, intelligence, personnel well-being, and logistics.

This summary is confined to the technology base (the DOD term for R&D activities that support technology development), which includes allocations to the Army, Navy, Air Force, and Advanced Research Projects Agency (ARPA). The technology base is organized into the following budget categories:

- 6.1 Military Science
- 6.2 Exploratory Development
- 6.3A Advanced Technology Development

The 6.1 effort is basic research that examines fundamental principles and expands scientific understanding. It is managed by the Office of Naval Research (ONR), the Air Force Office of Scientific Research (AFOSR), the Army Research Office (ARO) and ARPA. While most of the 6.1 funding (about 60 percent) goes to universities, a significant amount is in the form of contracts to in-house, industrial, or nonprofit laboratories. Almost all 6.1 research is unclassified and publishable, although it addresses topics that could have major effects on future military systems. In addition to planning and funding research activities, ONR, AFOSR, and ARO maintain and staff offices in London and Tokyo to keep active information channels open to foreign researchers.

Exploratory Development (6.2) is applied R&D and generally is aimed at meeting near-term national security needs. This work explores the feasibility of new or improved materials and fabrication processes and demonstrates practicality and limits. Normally, these projects are not tied to specific military systems and require the same tools and techniques as does basic research. The major goal is to enhance the technology knowledge base, which forms a menu for designers of advanced or upgraded weapons systems. As such, the 6.2 program is the workhorse of the military's R&D and hence has a larger budget than does the 6.1 program. The services emphasize joint planning and implementation of their 6.2 efforts. ARPA has a separate 6.2 budget, but its activities are coordinated with related joint-service projects.

Advanced Technology Development (6.3A) concentrates on highly significant technology areas, making and testing major components or even entire systems to gain confidence and credibility before final application to a military weapons system. These advanced programs, which can be very large, tend to conduct R&D that is structures- or device-oriented and therefore are not included in this inventory.

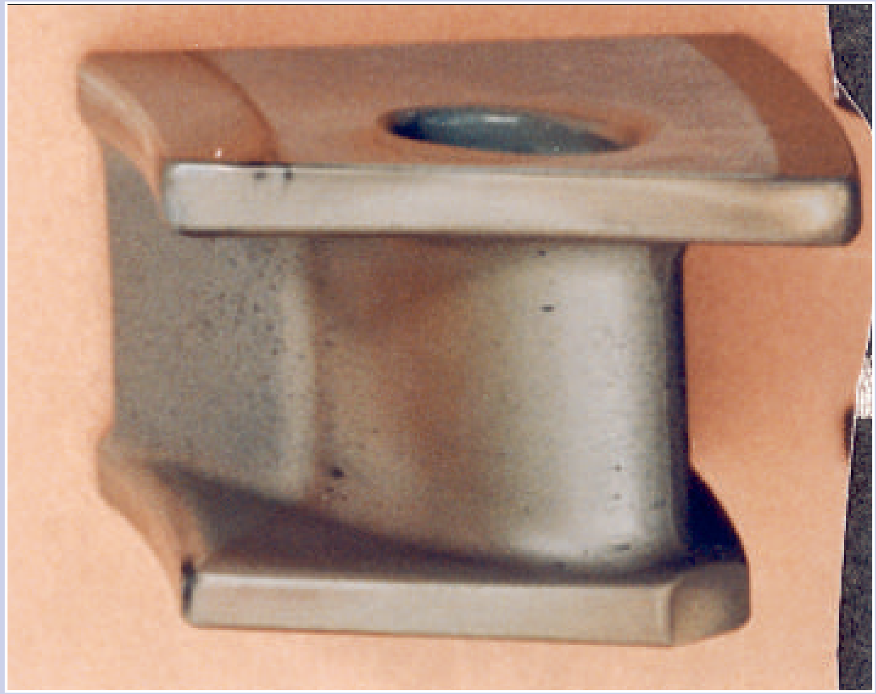
The DOD technology base includes major efforts to synthesize, improve, and test conventional materials, as well as development, processing, and characterization of advanced materials. Activities involving conventional materials focus on bearings, lubricants, hydraulic fluids, paint and other anti-corrosion coatings, steel, aluminum alloys, seals and sealants (e.g., elastomers), silicon for electronics, survivability and lethality testing, nondestructive evaluation (NDE) for use in the field, and field maintenance and repair methods. Research on advanced materials, by nature long-term, involves processing science and engineering, the key challenge in application of these materials.

The materials R&D programs of the three services exhibit some similarities, but each is oriented toward specific mission needs. For example, all the services emphasize processing R&D aimed at improving materials reliability and maintainability and decreasing costs without impairing performance; however, the programs emphasize different materials.

In the Army, the major unit involved in materials R&D is the Army Research Laboratory (ARL) Materials Directorate, which spends over half of its exploratory development budget in-house. The Army also allocates significant funding directly to other ARL directorates, the ARO and to research, development, and engineering (RD&E) commands such as the Soldier Systems Command, the Missile Command, the Armament RD&E Center, and the Tank and Automotive RD&E Center. The Army emphasizes structural and/or functional materials for applications involving ground vehicles (e.g., armor/anti-armor, tanks, propulsion, and lightweight structures); tactical missiles (e.g., guidance and control, seeker domes, windows, and propulsion); helicopters (e.g., lightweight armor and structures, small engines, and fatigue life); and ground personnel (e.g., lightweight body armor, clothing, and chemical/biological agent protection).

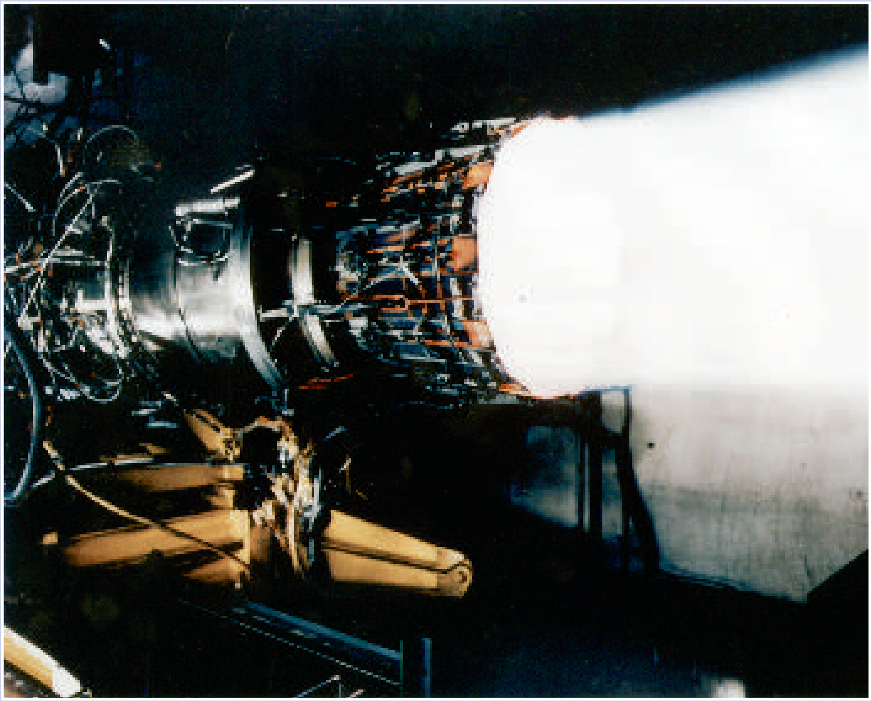
The Navy plans and funds all its 6.2 work out of ONR; about half of the funding is allocated to in-house laboratories. The Navy concentrates on materials for surface ships (e.g., hull steels, propulsion systems, and protection against salt-water corrosion) and submarines (e.g., high strength-to-weight-ratio pressure hulls and reduced signatures). The Navy also concentrates on materials for carrier-based aircraft (e.g., salt-water corrosion protection, carrier landings and takeoffs); strategic ballistic missiles (e.g., re-entry vehicle heat shields and nosetips, size restrictions); air- and sea-launched tactical weapons (e.g., ceramic radomes, infrared seeker domes/windows, and high-temperature airframe components); and Marine aircraft and vehicles (e.g., engines for lifting).

The Air Force plans and funds its 6.2 materials and processes program out of the Wright Laboratory Materials Directorate; about a third of the budget is allocated to in-house laboratories. Some focused efforts are performed in or funded by other Air Force research centers. The Air Force focuses on materials for fixed-wing aircraft of all types (including heavy-lift transports, fighters, and bombers), strategic missiles (e.g., re-entry vehicles,



Retrofitted Ceramic Parts to Save DOD Millions

Fielded military systems are being retrofitted with components made of state-of-the-art structural ceramics, which are expected to be more durable and require less maintenance than metal parts. About a dozen systems have been targeted in ARPA's Ceramic Insertion Program (CIP); savings of at least $100 million in total life-cycle maintenance costs are expected. The retrofitting effort was made possible by advances in design and fabrication of parts that are made of novel materials but still meet original equipment specifications and dimensional tolerances. The CIP has accelerated dual-use spin-offs of this technology for the commercial market. For example, ceramic nozzles (illustrated in photo) made for Air Force auxiliary power unit (APU) turbines will be incorporated into APUs for many commercial aircraft, including Boeing's 737, 757, 767, and 737-X, and McDonnell Douglas' MD-80 and MD-90. Similarly, it is expected that incorporation of ceramic valves, cam followers, rocker arms, and injector plungers into existing diesel-propelled howitzers will pave the way for retrofitting of these components into commercial diesels.



New Composite Extends Operational Life of Afterburner Nozzles

Ceramic-matrix composites developed by the Air Force have enabled a 900 percent increase in the operational life of afterburner nozzle components on aircraft turbine engines. Afterburners provide a quick power boost, which is augmented by a system of flaps and seals in an adjustable nozzle that can be partially closed to intensify the velocity of the exhaust. While nickel-based superalloy flaps and seals can tolerate the temperatures of conventional turbines, advanced engines operate at temperatures beyond the capability of superalloys, which tend to warp, crack, and fail after only one-third of their design life. The new composite material combines silicon carbide fibers in a carbon matrix. The fibers provide tensile strength and durability while closely matching the matrix in thermal expansion rate. The matrix provides stiffness and high-temperature resistance, and a silicon carbide coating protects against oxidation. In addition to their outstanding heat resistance and damage tolerance, ceramic-matrix composites offer greater toughness than do the monolithic ceramics as well as significant life-cycle cost savings over conventional flaps and seals. The first application for the composite flaps and seals is in the F414 engine upgrade for the Navy F-18 Hornet. An ARPA-funded program is developing oxide-oxide ceramic-matrix composite flaps and seals for afterburner nozzles on the Air Force F110 engine family for the F-16 aircraft. Life-cycle cost savings for one F110 engine are expected to total $9.3 million.

solid propellant launchers), satellites, aircraft armament (e.g., precision-guided missiles), and materials for electronic and electro-optic devices.

ARPA's emphasis is unique. Its mission is to research concepts that involve high risk -- perhaps too high for the services to justify -- but may offer a high payoff. Strictly a funding agency, ARPA has no laboratories, although it does support research at the service laboratories.

Materials R&D Related to National Priorities

Aeronautical Materials Technologies

The entire Air Force R&D program as well as segments of the Army, Navy, and ARPA programs address the needs of aerospace customers, including civilian users of dual-use technologies. The program spans the R&D spectrum from basic research through demonstration projects. The services also provide direct support to deployed units for the solution of materials problems in the field. Materials and processes are developed for aircraft systems, including propulsion; for space and missile systems, including strategic weapons and spacecraft; and for tactical weapons. Current topics of emphasis include gas turbine engine propulsion, space systems, maintenance of aging systems, pollution prevention, and affordability.

Automotive Materials Technologies

Many of the materials and processes developed by the services are potentially applicable to automobiles. The Army is working to transfer DOD technologies to the Partnership for a New Generation of Vehicles (PNGV). The services also are interested in expanding the use of aerospace materials in automotive applications, because mass production will reduce materials costs and establish new vendors and suppliers for military systems. Lightweight aerospace materials and components are being used to reduce the weight of automobile body panels, and high-temperature-tolerant intermetallics and ceramics are being evaluated for use in automotive engines. In addition, processes developed for aerospace applications are being used to make advanced automotive components, in an effort to improve productivity and cost-effectiveness.

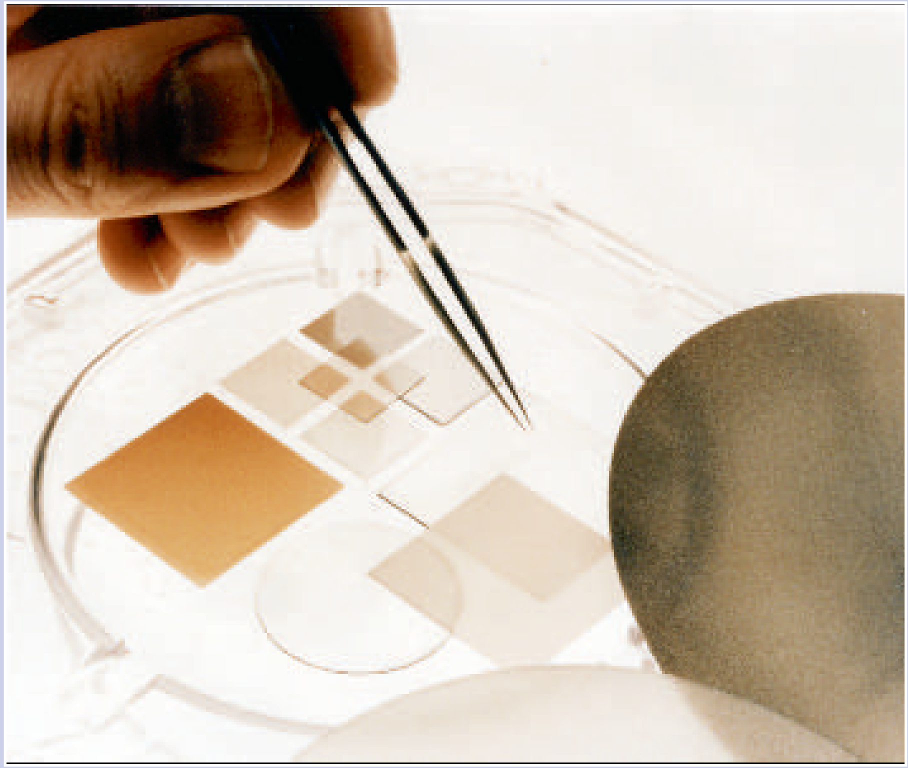
Electronic Materials Technologies

DOD has substantial interest in electronic materials and processes for use in radar systems, microwave equipment, infrared detectors, photonic devices and optical processors used for target acquisition, guidance, communication, electronic warfare, and data processing.

The Army is especially interested in ferro-electric (magnetic) materials for phased-array radars, which employ electronically steered radar beams instead of the traditional, manually moved parabolic antenna. The Navy has a particular interest in piezoelectric materials for transducers, diamond and diamond-coated ceramic transparencies for infrared windows, and superconducting wires for motors and films used in electronic devices.

Electronic materials under study by the Air Force include semiconductors, such as gallium arsenide, indium phosphide, and mercury cadmium telluride; nonlinear optical materials, such as zinc germanium phosphide; transparent materials, including zinc sulfide, zinc selenide, gallium arsenide, and germanium for sensor windows and domes, and high-temperature superconducting materials, such as yttrium barium copper oxide and thallium barium calcium copper oxide.

Intelligent Processing Produces Low-Cost, High-Quality Diamond Films for Thermal Management Applications



Through the development and application of "intelligent" processing methods, ARPA researchers have reduced the fabrication cost of thin-film diamond by more than two orders of magnitude, paving the way for advances in electronics and similar applications. By providing automatic on-line monitoring and feedback control of processing, these approaches can increase product yield and quality while reducing costs. This approach is ideally suited to production of low-cost, high-quality diamond films to be used in dissipating heat from products such as computers. Diamond, which has much higher conductivity than do traditional thermal management materials, such as copper, will enable at least an order of magnitude increase in the density of electronic components in single packages by relieving thermal loads over large areas. It is anticipated that costs can be reduced further through additional R&D, and that these cost reductions will make diamond films economically viable for both military and commercial applications.

Epoxy Coating System Doubles Rebar Service Life

The Navy spends approximately $300 million per year to repair waterfront concrete structures that have been damaged by corrosion of the steel reinforcement bars (rebar). Rebar typically is made of uncoated carbon steel. Bit, Navy testing has demonstrated that fusion-bonded, epoxy-coated rebar remains damage free and outperforms galvanized rebar as well as rebar protected by additives to the concrete. The Navy also identified optimum epoxy formulations and coating and handling procedures for the treated rebar. The epoxy is very robust and can be bent without cracking. This corrosion protection technology has been used in two Navy construction projects: a pier in New London, Conn. and a wharf at Pearl Harbor, Hawaii. The new coating is expected to provide an essentially maintenance-free structure over a 50-to-75-year service life, roughly twice the life span of the conventional material. The technology already is being used in commercial construction of bridges, rail systems, and piers under Navy procedures and specifications, pending issuance of commercial standards.

ARPA has a substantial program addressing several aspects of electronic technology. The Large Format Multichip Module program seeks significant reductions in size, weight, and cost of military electronic systems, along with enhanced performance and system simplification. The Advanced Electromagnetic Materials Thrust seeks new materials with revolutionary electrical and magnetic properties; major subelements address high-temperature superconductivity, magnetic materials and devices, and cryogenics.

Environmental Materials Technologies

DOD is concerned about the environmental impact of any material or process used in performing or supporting its missions, and this concern in reflected throughout the materials R&D effort. The emphasis is on preventing pollution from hazardous materials used in systems processing, fabrication, and maintenance.

Priorities include eliminating ozone-depleting chemicals, such as conventional fire suppressants and refrigerants used in aircraft systems; eliminating volatile organic compounds used in cleaning and degreasing metallic aircraft components; reducing use of metal processing methods that involve hazardous materials, such as anodizing acids; increased use of paints and paint removal processes that do not contain chromates or other hazardous materials; eliminating 17 hazardous chemicals identified by the Environmental Protection Agency; and developing non-polluting anti-icing materials for aircraft and runways.

Infrastructure Materials Technologies

Some DOD materials R&D is directly applicable to the Nation's infrastructure needs. This R&D includes projects on concrete for airfields and aprons; paints for maintenance of buildings and other structures on military bases; materials that can prolong the service lifetime of piers, docks, and pilings; and high-strength, low-alloy steels, and associated welding processes for bridges and commercial infrastructure. Some DOD materials technologies are being adapted for commercial infrastructure applications through consortia and partnerships seeking to commercialize use of advanced composites and NDE methods in bridges, highways, and buildings.

Interaction with the Private Sector

Where security allows, the results of all DOD science and engineering research programs are disseminated to the civilian sector by all the standard methods. The list of high-technology commercial components and systems that originated in military R&D is almost endless. Examples range from modern jet engines and strong, lightweight aircraft structures to long-lasting packaged food and integrated circuits. Because of the constant need to improve the performance of military systems, DOD always supports R&D activities that push the limits of technology; the resulting advances in materials, whether products of government, university, industrial, or nonprofit laboratories, are often of great benefit to the U.S. economy.

All DOD materials R&D programs have a significant extramural component. Support for private-sector basic research is provided by ARPA and the three services through the University Research Initiative (URI), which provides long-term funding essential to the stability of university research. More than two-thirds of 6.1 funds and all of the URI funds are spent in university and industry laboratories. More than half of 6.2 Exploratory Development (and most of 6.3A Advanced Technology Development) is conducted in industry laboratories. The DOD also supports the Small Business Innovative Research program in seeking unique breakthrough technologies to fulfill technical and mission needs.

With the Administration's evolving technology policy emphasizing dual-use concepts, a new approach in Federal R&D funding has evolved. Beginning with precompetitive consortia in 1991, expanding with the Advanced Materials and Processing Partnerships in 1992, and growing further with the Technology Reinvestment Project in 1993, consortia or partnerships of industry, academia, and government laboratories are encouraged to work together on substantial programs of mutual interest. Unlike previous relationships between

IHPTET is a collaborative program involving the Air Force, Navy, Army, ARPA, NASA, and industry. The focus is on developing turbine technologies that will enhance the affordability, durability, and performance of engines.

prime and subcontractors, these are true partnerships, where all participants share in the costs and the resulting technology. Because DOD funding is involved in these programs, the technology must address a military need, but prospective commercial utility is encouraged as a route to affordability.

An example is an unprecedented program involving technology teams from the Army, Navy, Air Force, ARPA, the National Aeronautics and Space Administration (NASA), and the U.S. aeropropulsion industry. The Integrated High Performance Turbine Engine Technology (IHPTET) program is an aggressive technology development effort designed to leapfrog technical barriers and deliver twice the aircraft propulsion capability of today's systems by the year 2003. A 30 percent increase in propulsion capability has been demonstrated in the first phase of the three-phase plan, which involves continuous technology transfer to both military and commercial users.

IHPTET is producing revolutionary advances in turbine engine technologies due to the synergistic effect of combining advanced materials, innovative structural designs, and improved thermodynamics. To double the thrust-to-weight ratio of propulsion systems, researchers are trying to replace superalloys with high-temperature-tolerant materials such as titanium aluminides, titanium-matrix composites, and ceramic composites. Achievement of IHPTET goals will result in the introduction of revolutionary aircraft cruise missiles and ensure continued U.S. preeminence in the increasingly competitive international marketplace for aircraft engines.

The advantages of the partnership approach also are illustrated by ARPA's efforts to expand the utility and reduce the costs of composites. The advanced composites developed by DOD offer tremendous performance benefits over metals, predominantly when used in aerospace structures and propulsion. The DOD cannot afford to lose those benefits in future military hardware -- nor can it afford the current costs. Therefore, ARPA is working with private-sector partners to make composites affordable, through drastic reductions in production and assembly costs, and mass production for commercial applications, such as automobiles.

The Army also is collaborating with the private sector to apply advanced materials technologies to automobiles. The Tank-Automotive RD&E Center houses the National Automotive Center, which helps transfer DOD technologies to the PNGV. Representatives from the Army and Air Force materials directorates are assigned to the PNGV Technical Panel.

The Navy collaborates and cooperates with diverse defense industries, including manufacturers of radar systems, aircraft, ships, and submarines, as well as primary materials suppliers and materials R&D companies that work with materials such as steel, aluminum, specialty metals (e.g., titanium and superalloys), and composites of all types. Component and major subsystem industries, such as turbine and diesel engine manufacturers, also develop advanced materials using internal and Navy support.

Materials R&D Base Programs

Industry Adopts Navy Spray Forming Process For Alloy Parts

Many U.S. manufacturers are considering use of the Navy's novel spray forming process, which has reduced the costs of seawater piping components by up to 50 percent while also enhancing performance. The innovative process solved a major problem for the Navy, which previously relied on complex and expensive methods of fabricating machinery system components out of high-strength, corrosion-resistant alloys. The spray forming process was developed in collaboration with the private sector. Research with Osprey Metals, Ltd. (U.K.), resulted in excellent alloy deposition rates and yields of about 75 percent, twice the former rate. A Navy-industry-university team developed and produced the "intelligent" spray-forming hardware, software, and sensor systems. A Navy facility for the production of asymmetric, near-net-shape components, the only one of its kind in the world, was built recently in Annapolis, Maryland, and its capability to produce high-quality, complex components, such as tooling dies, has been demonstrated. Companies using the facility include Ford Motor Co., McDonnell-Douglas Aerospace, EG&G Mechanical Components Group, and Caterpillar, Inc. These activities have spawned several new initiatives, including a program designed to meet the Navy's piping needs and establish a U.S. industrial base.

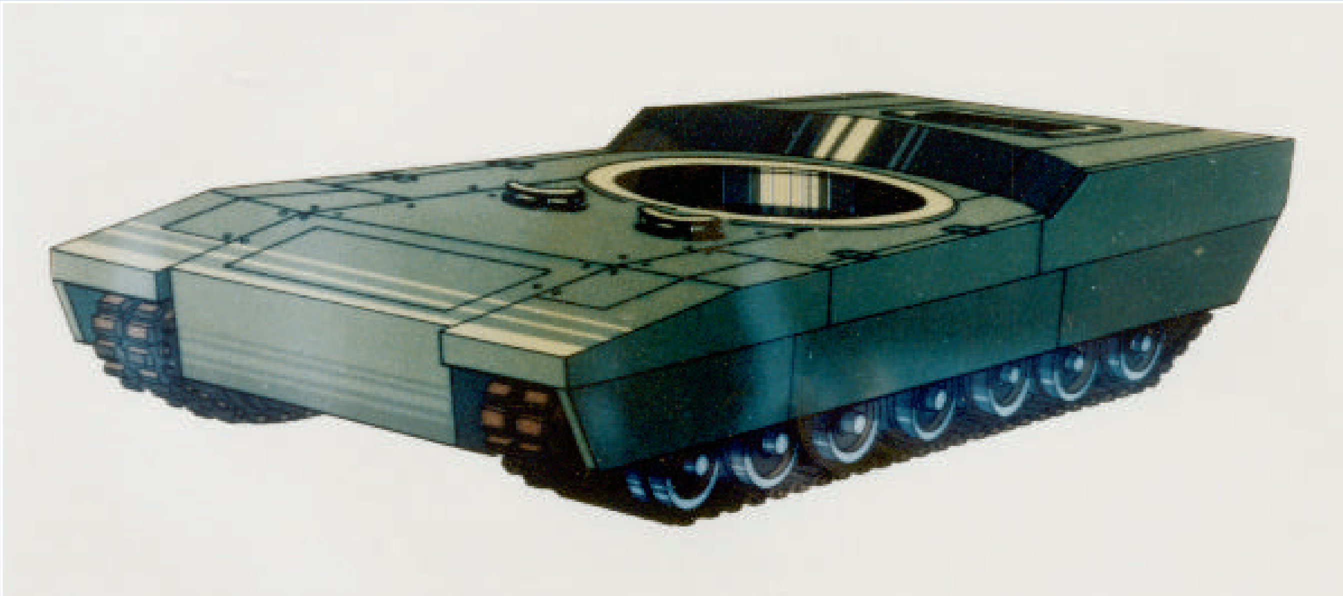
The Air Force, through extensive interaction with the private sector, provides leadership and vision for the aerospace industry's investment in materials and processing research. Air Force support for materials R&D leverages industry investments to maximize returns and ensure "critical mass" funding levels. There is also a growing effort to transfer DOD technologies to commercial industries through Cooperative Research and Development Agreements, in order to extend the aerospace industrial base and achieve market economies for needed military technology.

The Army

The overall objective of the Army's materials processing and manufacturing (MPM) activities is to support development of lethal, highly mobile, rapidly deployable, conventional land forces that also provide as much protection as possible to U.S. soldiers. Because of volume and weight constraints of air- and sea-lift resources and the basic Army need for weapons and equipment that can be carried by soldiers, the size and weight of weapon systems must be reduced while improving, or at least maintaining, other battlefield capabilities.

A major thrust of the Army MPM programs is the development of lightweight materials that will improve the individual soldier's chances of survival against the ballistic, chemical/biological, and laser threats encountered in conventional warfare or operations other than war. Such advances will demand lightweight advanced materials with high strength and temperature tolerance that can be tailored to function in demanding environments. Therefore the Army is expanding its efforts in processing and manufacturing of not only high-strength metals but also structural composites, polymers, and ceramics.

Advanced materials contribute to the survivability of the force in many ways. Ceramics and composites offer increased ballistic protection for armored vehicles while achieving weight savings of up to 30 percent relative to traditional materials. Increased ballistic



Army Pioneers Use of Composites for Weight Reduction in Armored Vehicles and Other Fielded Systems

Composite materials offer the potential to reduce the weight of U.S. military systems by some 30% while also reducing their signature and providing the same level of personnel protection as do metals. Applying this technology to existing systems, the Army's Composite Armored Vehicle-Advanced Technology Demonstrator (CAV-ATD) integrates improvements in structural parameters, ballistic protection, and signature reduction into highly engineered hull and turret structures. The incorporation of advanced materials into fielded Army systems requires the development of new processing technologies that can handle sections much thicker than the traditional fiberglass board used for repairs. The Smart Weave process, developed for the CAV program, enables monitoring of thick-sectioned, resin-transfer-molded composites during their manufacture. The process is designed to ensure that the finished component will achieve the performance engineered into it. Demonstration vehicles with composite components manufactured using this process are being evaluated.

protection also has been achieved by developments in, and modifications of, high-hardness metals. Recent advances in conversion of highly ordered polymers into textile fibers with outstanding strength-to-weight ratios will lead to development of body armors, helmets, and shelters that are lighter in weight than conventional ordnance but retain -- and in many cases increase -- ballistic protection. At the same time, advanced coating technology offers protection against lasers and increases the scratch resistance of ballistically protective goggles, and advanced materials and coatings help reduce the signature of U.S. forces across the electromagnetic spectrum (preventing detection by radar, infrared detectors, etc.).

A unique Army area of responsibility, which helps safeguard all U.S. military forces, is the development of materials that provide protection from, or are compatible with, chemical and biological warfare agents. This effort includes the study and prevention of the permeation and/or deterioration interaction of various agents and decontaminants coming in contact with engineering materials. For clothing, protection against chemical agents will be enhanced by controlled permeability barrier materials made possible through computer-aided design of the molecular structure of polymers.

Materials development within the Army also helps increase the lethality of weapons systems. High-performance heavy alloys for penetrators and warheads are essential in combat against advanced armor systems. Advanced tungsten alloys, made of metal powder that is hot-pressed into the required shapes, may offer an environmentally benign alternative to the depleted-uranium penetrators used in current anti-armor munitions. Similar in density to uranium, tungsten is neither radioactive nor toxic. The goal is to develop, by the year 2000, full-sized tungsten penetrators that achieve performance equal to that of the current technology. Army researchers also are developing gun tube liners made from tantalum alloys and silicon carbide, which may enable the use of liquid propellants and provide for increased discharge velocity as compared to the current steel technology.

Material developments are also needed to improve the mobility of U.S. forces. Researchers are trying to reduce the weight of phased-array radars by making components out of low-density ferroelectric (magnetic) ceramics instead of iron. In addition to their lightweight structures and armor that will make the force more mobile and deployable, advanced materials can improve power-plant efficiency and thereby reduce the logistical burdens on deployed forces. The use of ceramics and ceramic-matrix composites in low-heat-rejection propulsion systems not only will reduce the fuel requirements of Army vehicles but also will help reduce vulnerability by minimizing their infrared signature.

The Navy

The Navy science and technology program in materials and processes supports the needs of naval surface and undersea platforms, seaborne and land-based anti-submarine warfare aircraft, carrier-based fighter and attack aircraft, tactical and strategic missiles, spacecraft, and other naval-specific materials requirements of the Marine Corps and Navy Sea-Air-Land teams. To accommodate this breadth in applications, the structural materials program is comprehensive, encompassing metals, intermetallics, metal- and organic-matrix composites, polymers, fine ceramics, and ceramic-matrix composites. The program also addresses many functional materials, such as materials that are transparent to electromagnetic radiation from optical through infrared to radio frequencies, piezoelectric and magnetic materials, and electrical materials.

Of course, maritime operations require that the Navy pay special attention to salt water corrosion, erosion, environmentally assisted mechanical failure, and wear processes. These

Composite Heat Sinks Increase Spacecraft Reliability

The reliability of DOD's Clementine spacecraft, which carried a lightweight sensor camera that mapped the dark side of the moon (and thereby demonstrated the capability to detect a cold object, such as a missile) was improved by the use of a novel graphite-aluminum composite material in the orbiter's heat sinks. This material resolved a major problem in electronics, where the trend toward higher power and denser circuitry has demanded new methods for removing waste heat. The electronics package on the Clementine lunar orbiter had a potential problem with overheating, which could have caused the systems to fail. The composite materials, characterized by high thermal conductivity, were fabricated into the heat sinks (small plates) in two electronics units aboard the Clementine. The improved conductivity permitted the components to function at a reduced temperature for a given operational power, thereby improving reliability. The composite heat sinks also were 8 percent lighter in weight than their aluminum alloy counterparts. The flight test provided valuable quality control, space qualification data, and design experience, all of which will help reduce the risks involved in using the new technology in future satellites.

issues pervade all aspects of the Navy program. A few illustrative efforts now under way are discussed in the following paragraphs.

Navy and other DOD systems, from satellite batteries to radar amplifiers and solid-state processors, increasingly rely on advanced management of the heat loads created by ever-denser circuitry. The heat must be dissipated, or the electronics may fail. This problem has driven system designers to liquid and other active cooling systems, although from the standpoint of reliability, simplicity, and ease of logistical support, passive thermal-management systems would be more desirable. The Navy has taken a lead role in the development of ultra-high-thermal-conductivity materials, especially graphite fibers and pyrolytic carbonaceous structures, which promise to make passive thermal management feasible. Development of advanced fibers and metal- and ceramic-matrix systems incorporating the fibers is to be a major thrust of the program. Researchers are evaluating novel processing approaches for the use of high-thermal-conductivity fibers in printed wiring board components that have both very high conductivity and controlled thermal expansion properties. Other applications under study include thermal planes (pieces of metal that conduct heat away from a circuit board) in aircraft electronic systems, satellite batteries and other radiators, microelectronic heat sinks, and heat distribution in systems for infrared signature control.

The Navy also is developing advanced process technologies that will permit the rapid, affordable prototyping or replacement production of complex components made of advanced materials. Scientific advances in solid free-form processing of titanium and other reactive alloys are being exploited for potential Navy applications, while more mature molten metal spray-forming processes have been automated with "intelligent" controls and utilized to supply superalloys in tubular shapes for submarine programs. Other projects have exploited largely commercial developments in high-strength, low-alloy steels by developing the welding processes and materials needed to adapt these materials to ship hull fabrication. These materials have saved the Navy more than $150 million in hull construction costs and are being evaluated for bridges and other commercial infrastructure applications.

To improve corrosion control, scientists are examining the basic mechanisms of corrosion in the marine environment and the potential for novel approaches to improving the corrosion resistance of alloys, such as molybdenum-containing aluminum alloys. Continued affordable acquisition and operation of naval assets depends on development of corrosion-resistant, unusually tough alloys and composites for use in naval aircraft landing gear, naval aircraft and ship structures, turbine engines for both aircraft and ships, and shipboard piping. Equally important to affordable operation will be increased understanding of the processes of wear and erosion and the development of innovative materials that can reduce wear and erosion of materials as well as frictional losses. These and other product-life prediction and management projects have been brought together in a major initiative aimed at developing maintenance techniques based on the condition and predictable remaining life of individual assets. Such methods would increase operational safety while simultaneously eliminating unnecessary and costly scheduled maintenance.

Functional materials under study include advanced piezoelectric materials, which respond to pressure or other external triggers, for acoustic transducers; diamond and diamond-coated ceramic transparencies for the windows housing heat seekers on missiles (diamond is both wear resistant and transparent to infrared radiation); thermal-shock-resistant nanocrystalline ceramics for high-speed missile radomes; magnetic materials for sensors, bearings, and electronics; and thermoelectric materials for ship and submarine refrigeration and cooling. In addition, high-temperature superconducting materials are being developed and demonstrated in naval exploratory systems ranging from magnetic anomaly detectors for anti-submarine warfare to motor-generator coils for propulsion or mine clearing.

The Air Force

The Air Force Materials and Processes R&D program, conducted by the Materials Directorate of the Wright Laboratory, develops materials, cost-effective processes, NDE technology, and "intelligent" processing technologies for advanced materials to support the entire Air Force mission, which involves the use of aircraft, weapons, missiles, and spacecraft.

The materials R&D program is designed to provide the technologies needed for both upgrades/modifications and advanced systems. These technologies include propulsion, electronics, and photonics, with an overall emphasis on performance, affordability, and supportability. Systems concepts evolve informally through direct interactions between researchers and systems offices or logistics centers, and formally through the plans prepared by the major commands and the Air Force Materiel Command. Through this process, which assesses threats, capability needs, and technological opportunities, the R&D program is planned to meet Air Force needs.

The materials R&D program is organized into three key technical thrusts. These thrusts are structured to meet Air Force capability needs and are reviewed and revised periodically to reflect changing priorities.

Diamond Domes May Enable Development of Hypersonic Missiles

Synthetic diamond material with properties approaching those of natural diamond has been fabricated by Navy researchers in the size and shape required for Sidewinder missile domes (the windows covering the missile's infrared heat seekers). Naturally occurring, single-crystal diamond has optical, mechanical, and thermal properties that would make it the most durable and shock-resistant material possible for missiles if it were available in the required sizes and shapes. Such material would survive the thermal shock of Mach 4+ flight speeds (four times the speed of sound, which varies with altitude) and allow long-wave infrared guidance to be incorporated into hypersonic missiles. Using chemical vapor deposition processes, Navy researchers grew a diamond large enough (about 3 inches in diameter) and are trying to characterize the material and polish it for optimum light transmission. In addition to making hypersonic missiles feasible, diamond domes would increase military readiness by improving resistance to rain and dust erosion and reducing the need for dome replacement.

Thrust 1: Materials and Processes for Structures, Propulsion, and Subsystems

Thrust 1, the largest effort, encompasses development of materials and processes for a wide range of applications in aircraft, space, and missile structures requiring properties such as load bearing, thermal management, light weight, reduced life-cycle cost, and lubrication. Some activities target nonstructural applications for mechanical subsystems that support all Air Force systems.

Materials and processes currently under development include carbon-carbon for lightweight satellite needs and for re-entry vehicle nosetips and leading edges; an aluminum alloy that will reduce aircraft and spacecraft weight; titanium aluminides and nickel aluminides for hypersonic vehicles, advanced engines, and improved engine maintainability; reduced-cost processing of advanced nonmetallic composites, as well as high-temperature-tolerant composites that can replace metals and provide weight savings; and advanced hydraulic fluids, low-friction films for bearings, advanced lubricants for subsystems, and thermal control coatings for space vehicles.

Thrust 2: Materials and Processes for Electronics, Optics, and Survivability

Thrust 2 encompasses development of materials and processes that meet requirements for advanced avionics, communications, reconnaissance, surveillance, intelligence, signature control, and electronic combat, as well as laser-resistant electromagnetic materials for transparencies and eye protection, sensors, and aircraft and spacecraft structures. The objectives are to improve the electronic, optical, and electro-optic devices and subsystems for aircraft, missile, and space systems; and enhance the survivability of crews, sensors, aircraft, and space systems.

Materials and processes under development include gallium arsenide, to reduce the cost and improve the reliability of advanced X-Band and space-based radar systems; indium phosphide for the next generation of materials for radar, space-based communication, photonic, and electronic applications; silicon carbide, which, because it remains active at very high temperatures, will enable the detection of cold targets (current sensors detect warmth); and nonlinear optical materials, such as zinc germanium phosphide, for use in infrared, visible, and ultraviolet countermeasure systems. Other materials (germanium, zinc sulfide, zinc selenide) will be used in improved sensor domes critical to current and future systems. High-temperature superconducting materials, such as yttrium barium calcium copper oxide and thallium barium calcium copper oxide, will enable advances in infrared focal plane array processors (components of imaging systems), digital microwave receivers, and advanced radar and communication circuits. Laser-resistant materials will provide protection for crews, sensors, and structures against increasingly challenging threats, as lasers become tunable and more powerful.

Thrust 3: Materials and Process Technology for Sustainment

Thrust 3, the primary interface with users, provides NDE methods and devices for detection and monitoring of service-initiated damage or deterioration, and for ensuring optimum production of Air Force systems; on-site personnel and technical support for operating and maintenance organizations when materials and processing problems occur in the field; and component material failure analyses. Activities in this thrust area also develop data that enable the transfer of materials technologies to organizations that develop, operate, and maintain Air Force systems. Environmental technologies also are addressed in this thrust, which seeks to reduce by 50 percent the use of hazardous and/or toxic materials in material processing and repair and maintenance procedures.

As Air Force systems age, increased emphasis will be placed on areas such as corrosion detection, control, and repair; improved coating systems for corrosion protection; detection and repair of multi-site damage to aircraft structures; and failure analysis aimed at predicting and extending the life of aircraft and engine components.

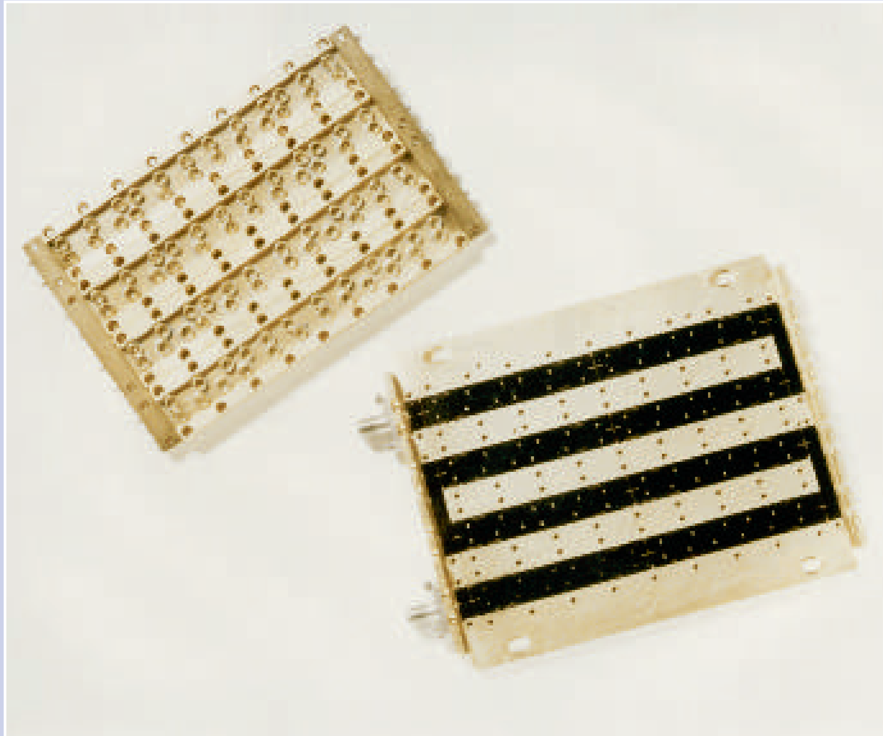
ARPA

Materials research at ARPA is concentrated in just a few areas --those with the highest potential payoff for military systems. The approach is similar for each new program. Upon discovery of a breakthrough material, process, or phenomenon, ARPA moves in to conduct basic research, advancing scientific knowledge and identifying early and influential applications. Then, as soon as possible, a demonstration prototype of a chosen application is built, and manufacturing and supporting technologies are developed. As the major goals are achieved, the program is phased out, and new opportunities are pursued. All programs incorporate "intelligent" processing concepts, advanced on-line process controls, and the latest materials theory, modeling, and simulation tools, many of them developed by ARPA.

Current activities emphasize processing improvements. Advanced structural materials, especially composites, are very strong, lightweight, and stiff but far too costly; for these materials, therefore, the emphasis is on development of affordable manufacturing and fabrication techniques. For materials other than composites, processing research is oriented toward finding ways to manufacture low volumes at costs comparable to those of high-volume production; solid preform fabrication; vapor deposition of thin films; development of flexible tooling (aimed at computer directed fabrication of single, complex shapes); and large format multichip modules.

ARPA researchers also are developing new functional materials. Advanced electromagnetic materials are sought with potentially revolutionary electrical and magnetic properties. High-temperature superconductors, thin-film magnetic memory, and cryogenics technologies will provide sensing, communications, and computational devices that will have a major

"Smart" Filter Permits Concurrent Use of Radar Technologies



A "smart" ceramic filterbank has been developed that reduces military aircraft vulnerability by allowing pilots to use radar warning receivers (RWRs) and radar weapons systems at the same time. Unfiltered emissions from radar weapons systems can interfere with RWRs, so until now pilots have had to switch off the receivers when using the weapons. Developed with support from the ARPA High Temperature Superconductivity program, the new multi-channel emissions filtering capability means that the two systems can operate simultaneously, and the pilot can be alerted to radar surveillance at all times. The filterbank consists of several fiber-optically controlled high temperature superconductivity (ceramic) filters. The system allows for selective interference filtering by switching filters for different channels on and off. The subsystem has passed initial and operational testing, permitting near-term field demonstration and qualification.

impact on military systems in the next decade. Another program is devoted to developing new materials with breakthrough optical properties (e.g., selective absorption of certain wavelengths of light) for eye protection, data storage, and signal processing, as well as a breakthrough fabrication process for binary optics, spherical optics, diffractive optics, and gradient index optics.

Major Research Facilities and Centers of Excellence

The Army

The following laboratories are well-equipped for most aspects of materials research. Each facility has unique capabilities. For example, the ARL Materials Directorate has a laboratory specializing in ion implantation.

Materials Directorate
Army Research Laboratory
Aberdeen Proving Ground, MD

Soldier Systems Command
Natick, MA

New Composite Resin Reduces Aircraft Damage and Costs

A new resin developed by Air Force engineers has solved a recurring heat damage problem on the fuselage trailing edges (the rear edges of the wings) of the F-117A stealth fighter. Hot exhaust gases from the aircraft's engines, which are embedded in the wings, were charring and ruining the trailing edges. The Materials Directorate developed the AFR700B resin and supplied it to the F-117 System Program Office at the Sacramento Air Logistics Center, which used the material as the matrix for the organic-matrix composite wing edges. The center fabricated the trailing edge parts and sent them to the Consolidated Test Facility for a flight test. The flight test proved the AFR700B parts performed satisfactorily -- increasing the high-temperature tolerance of the trailing edges by 66˚C and they were accepted for use on all F-117A aircraft. Use of the resin will save the Air Force at least $15 million in F-117A acquisition costs and $50 million in life-cycle costs. Other applications, such as commercial propulsion systems, may emerge as well.

Armament Research, Development and Engineering Center
Dover, NJ

Tank-Automotive Research, Development and Engineering Center Warren, MI
Missile Command
Huntsville, AL

Benet Weapons Laboratory
Watervliet, NY

The Navy

Naval Research Laboratory
Washington, DC

Naval Surface Warfare Center
Carderock Division
Annapolis and
White Oak, MD

Naval Surface Warfare Center
Dahlgren Division
Dahlgren, VA

Naval Air Warfare Center
Aircraft Division
Warminster, PA and Patuxent River, MD

Naval Air Warfare Center
Weapons Division
China Lake, CA

The Air Force

The Air Force has established the most comprehensive aerospace materials and processing research facility in the world in the Wright Laboratory Materials Directorate in Dayton, Ohio. The unique capabilities of this facility complement the Air Force materials and processes program strategy by balancing selected in-house research capabilities with collaboration with other government and industry experts.

The Wright facilities meet the full spectrum of Air Force needs in areas that include structural materials (metals and nonmetals); nonstructural materials (lubricants, coatings, seals, etc.); electronic, optical, and electro-optical materials; and materials testing, evaluation, and failure analysis (including rain erosion and laser testing). Facilities include:

- Space Combined Effects Primary Test and Research Equipment Facility, used to study of the effects of space exposure on thermal control materials;
- X-ray Computed Tomography Facility, used for development of advanced X-ray techniques for inspection of Air Force systems;
- Rain Erosion Facility, used for determining the susceptibility of advanced materials and coatings to high-velocity rain erosion damage; and
- Laser Hardened Materials Evaluation Laboratory Facility, used to test and evaluate the effects of lasers on advanced materials and to evaluate laser-resistant materials and techniques.

External Centers of Excellence

Numerous specialized university research centers receive DOD funding, often through the University Research Initiative. An illustrative sample is listed here by technical specialty:

High Loading Rate Effects on Materials
U.C. San Diego
La Jolla, CA

Manufacturing of Composites
Univ. of Delaware
Newark, DE

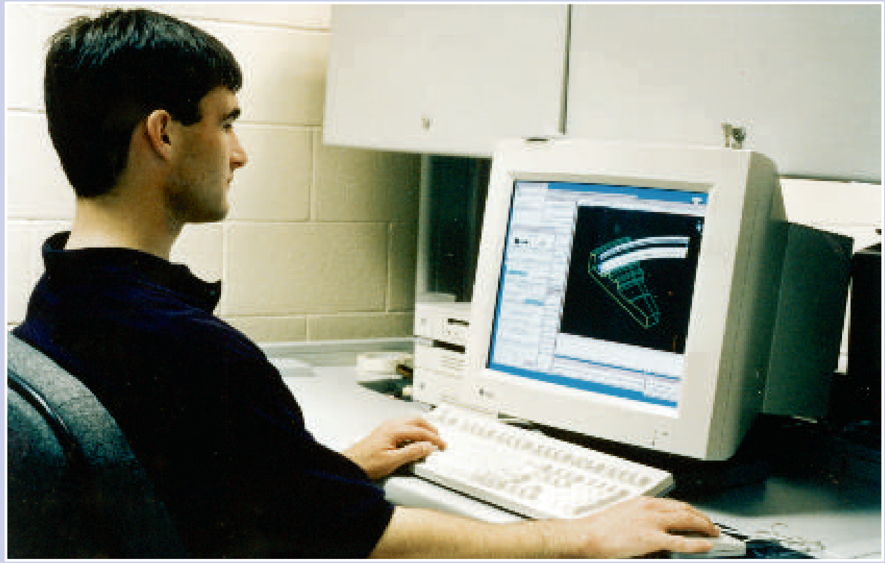
Synthesis, Interfaces and Mechanics of Composites
Univ. of Illinois
Urbana, IL

High Temperature Ceramics-Interphase Interfaces
Case Western Reserve Univ.
Cleveland, OH

Processing and Mechanical Properties of High Temperature Composites
U.C. Santa Barbara
Santa Barbara, CA

II-VI Compounds - Fabrication, Microstructure, and Properties (E/O devices)
California Institute of Technology
Pasadena, CA

Interfacial and Thin Film Chemistry in Electron Device Fabrication Columbia Univ.
New York, NY



Software System Enhances Aircraft Material Inspection Planning

Air Force engineers have developed and patented a rapid method of generating the scan-plans used in inspecting the condition of materials in aircraft components, reducing the time required to create the computer-generated diagrams from months to days. Scan-plans historically have been difficult to create and maintain, requiring labor-intensive manual measurements and translation of these data into a computer code. The new computer software system, AUTO-INSPECT, combines an expert system, a process planner, and a computer-aided design (CAD) system that translates the geometry of the CAD-generated drawing of the solid body shape into a scan-plan. Under an agreement with Systems Research Laboratories in Beavercreek, Ohio, the automatic scan-plan generation system will be applied to the F100-PW-229 aircraft engine, which has 15 parts. The automated system is expected to reduce per-part plan preparation time from 10 weeks to one week. The inspection planner may also be used with many other military and commercial aircraft parts such as wheels, landing gear, and large-area components including wings and flight control surfaces.

Nanocomposites for Electronic Application
Penn State Univ.
University Park, PA

Dilute Magnetic Semiconductor Heterostructures
Purdue Univ.
Lafayette, IN

Synthesis and Study of Ultra-Small Structures and Devices Derived from Molecular Materials
Harvard Univ.
Cambridge, MA

Organosilicon Polymers
Atlanta Univ.
Atlanta, GA

Center for Advanced Construction Technology (Concrete, etc.) Massachusetts Institute of Technology
Cambridge, MA

Mechanical Properties of Structural Polymers
M.I.T.
Cambridge, MA

Micro/Macro studies of Fiber-Reinforced Composite Materials N.C. A&T Univ.
Greensboro, NC

High-Temperature Advanced Structural Composites R.P.I.
Troy, NY

Manufacture and Characterization of Silicon Carbide and Silicon Carbide Composites
Tuskegee Univ.
Tuskegee, AL

Advanced Electrical and Structural Polymers
Univ. of Mass.
Amherst, MA

Polymer Synthesis by Non-Redox Processes
Univ. of Pennsylvania
Philadelphia, PA

Electronic and Ionic Transport in Polymers
Univ. of Texas at Arlington
Arlington, TX

Center on Manufacturing Science of Polymeric Composites
U.C. San Diego
La Jolla, CA

Layered Nanocomposites by Biometric Processing
Case Western Reserve Univ.
Cleveland, OH
Dynamic Behavior of Brittle Materials
Brown Univ.
Providence, RI, and U.C. San Diego, CA

Smart Structural Systems - Mesoscale Integration
Princeton Univ.
Princeton, NJ;
M.I.T.
Cambridge, MA;
Drexel Univ.
Philadelphia, PA;
U.C.L.A., Los Angeles, CA;
Case Western Reserve,
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Department of Energy

DOE Primary Organizational Units Sponsoring R&D Programs in Materials Science and Technology:

Office of Energy Research (ER)

Office of Basic Engery Sciences/Materials Science
Office of Fusion Energy (OFE)
Office of Computational and Technology Research/Laboratory Technology Applications (LTA)

Office of Energy Efficiency and Renewable Energy (EE)

Office of Industrial Technologies (OIT)
Office of Transportation Technologies (OTT)
Office of Building Technologies
Office of Utility Technologies

Office of Fossil Energy

Office of Nuclear Energy

Office of Space and Defense Power Systems

Office of Defense Programs

Office of Environmental Management

Overview of Materials R&D Activities

The Department of Energy (DOE) supports the largest Federal materials R&D program of any agency. Advanced materials R&D is central to DOE's mission activities because the characteristics of materials limit the performance, economics, environmental acceptability, and safety of all energy generation, conversion, transmission, and conservation technologies. Therefore, the R&D effort is extensive, addressing virtually all classes of advanced materials in projects ranging from studies in fundamental condensed-matter physics to large-scale device fabrication.

Most of the research is carried out at government-owned, contractor-operated laboratories, although some is conducted by universities or industry. DOE also operates a number of National User Facilities, described elsewhere in this report, where researchers from universities, industry, and both DOE and non-DOE government laboratories conduct investigations in a broad variety of scientific disciplines.

Basic and applied materials research are integrated through numerous mechanisms. One of the most effective ways of achieving a two-way flow between basic and applied materials research is to locate both types of activities at the same national laboratory under common management. It is typical for individual DOE laboratory investigators to be funded by both basic and applied program offices for complementary basic and applied materials research tasks.

Internal coordination within the DOE materials R&D programs is achieved through formal coordination committees, topical contractor meetings, workshops, program reviews, laboratory management reviews, and other activities designed to assure effective coordination of complementary or related activities.

Many DOE units support materials R&D:

The Office of Energy Research supports a broad array of activities through its Office of Basic Energy Sciences, Office of Fusion Energy, and Office of Computational and Technology Research. The Basic Energy Sciences/Materials Sciences program focuses on developing the capability to discover technologically, economically, and environmentally desirable new materials and processes, and on the construction and operation of the instruments and facilities needed for such research.

"Buckyball" Molecules Form Basis for New Class of Materials

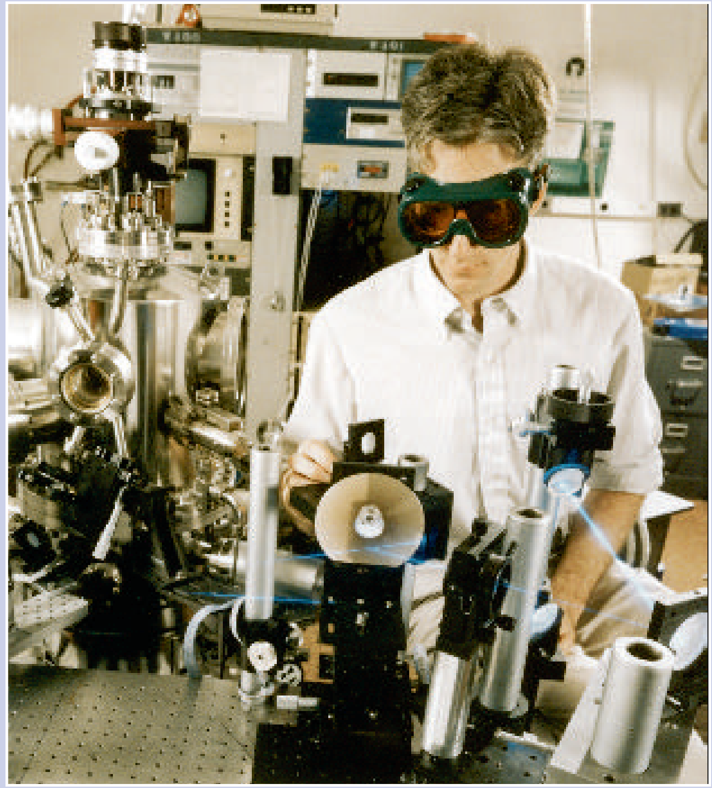
The "Buckyball" molecule first synthesized by DOE scientists finally has been modified, generating precursors to a new class of novel polymerized materials for applications ranging from battery electrodes to AIDS treatments. Buckyballs are molecules of 60 carbon atoms, an unusual structure that scientists had predicted but until recently never observed. In studying these molecules and experimenting with variations, researchers finally developed a methodology for controlled chemical modification of Buckyballs. The DOE researchers used computer-aided molecular design and experimental techniques to synthesize new Buckyball molecules that are chemically active precursors to a new class of materials. This work revealed the fundamental patterns of chemical modification of these novel compounds. The widely cited results now are being used by academic and industrial researchers to understand and predict the structure of Buckyball-based building blocks for new materials. Applications under investigation include electronic materials for battery electrodes; microporous materials for chemical- and gas-separation membranes and selective adsorbents; structural materials, such as composites for aircraft); and biomaterials (modified Buckyballs have been shown to inhibit activity of the virus that causes AIDS).

The Fusion Energy program is concerned with the development and validation of materials needed for fusion energy systems. The Laboratory Technology Applications program of the Office of Computational and Technology Research supports public-private partnerships designed to address needs for high-risk technologies important to DOE that industry cannot develop on its own.

The Office of Energy Efficiency and Renewable Energy conducts long-term, high-risk materials R&D through four offices focusing on industrial, transportation, building, and utility technologies. The overall goal is to develop the technologies needed for efficient use of existing energy supplies and expanded use of renewable energy sources. Areas of study include coatings and films, ceramics, solid electrolytes, elastomers and polymers, corrosion, superconductivity, and photovoltaics.

The Office of Fossil Energy seeks to develop advanced materials that will improve the performance, durability, and efficiency of fossil energy systems while reducing their cost and environmental impact. The materials R&D program focuses on high-temperature structural ceramic composites, structural alloys, coatings, and functional materials.

The Office of Nuclear Energy conducts materials R&D to support the design, development, production, and safety of reactor and radioisotope nuclear power systems for space and military



A DOE researcher mounts a sample computer hard disk drive on the Raman facility laser apparatus. Use of the rapid characterization Raman spectroscopy procedure is helping Seagate Magnetics of Fremont, Calif. develop improved amorphous hard carbon protective coating for hard disk drives. These coatings are key to the longevity of a drive unit.

New Thin-Film Characterization Tool Increases Product Yield

A rapid on-line materials characterization method developed by a DOE laboratory and an industrial partner has enhanced the quality of thin-film coatings and increased the company's product yield. The advance was made possible by development at Lawrence Berkeley Laboratory (LBL) of Raman spectral techniques (which involve scattering light off a surface) for characterizing thin films. The technology was adapted by LBL and Seagate Magnetics, a manufacturer of hard disk drives for computers, to make an optical testing method for characterizing protective thin-layer coatings on new products. The coatings, made of amorphous hard carbon, increase the hard drives' service life. The optical testing equipment employs sensors that monitor coating quality and provide feedback for continuous process control. Now installed on production lines, the testing equipment has helped maintain consistent coating quality and thereby increased yields of marketable product. The new testing technology also is being used in a multi-laboratory DOE effort to develop superhard carbon coatings for other applications.

Sales of DOE's Super 9 Chrome Alloy Top $100 Million

During the 1980s, DOE researchers were instrumental in the development of a superstrong alloy, Super 9 Chrome, now used worldwide as a standard means of improving the safety and reliability of equipment in coal-fired power plants. This alloy, made of 9 percent chromium, 1 percent molybdenum, and 90 percent steel, enhances the durability and performance of equipment under the severe temperature, pressure, and corrosion conditions typical of fossil fuel plants. DOE scientists received an R&D Magazine award based on peer reviews for this technology, which has been incorporated into American Society of Mechanical Engineers boiler and pressure codes and transferred directly to industry for commercial applications. Sales of this product exceed $100 million to date. Use of this alloy has enabled an increase in coal-fired power plant efficiency of more than 3 percent, resulting in a savings of more than $1.7 million per year in fuel costs for each typical (500 megawatt) power plant. The increased efficiency has the added benefit of reducing emissions of sulfur dioxide, nitrogen oxides, particulates, and carbon dioxide.

systems. The program addresses thermoelectric materials and devices for energy conversion, high-temperature heat source materials, materials systems compatibility, and safety-related materials characterization.

The Office of Defense Programs carries out materials R&D related to the safety of nuclear weapons development. Key topics include electronic and opto-electronic materials, management of hazardous materials, and development of new techniques for materials characterization and environmentally sound processing. Most of the R&D activities are applicable to conventional defense and civilian technologies.

The Office of Environmental Management sponsors development, demonstration, testing, and evaluation of new and improved materials for remediation system structural components, sensors, containment and separation systems, catalysts, and recycling efforts. Materials of interest include corrosion-resistant refractory materials, thin films, and ceramics.

Materials R&D Related to National Priorities

Aeronautical Materials Technologies

Much of DOE's basic materials research supports development of improved aerospace technologies. Relevant research topics include synthesis and processing of materials, corrosion prevention, welding and joining of metals and ceramics, high-rate and superplastic forming of lightweight metallic alloys, high-temperature structural ceramics and ceramic-matrix composites, nondestructive evaluation (NDE), and mechanical behavior and failure resistance of structural materials.

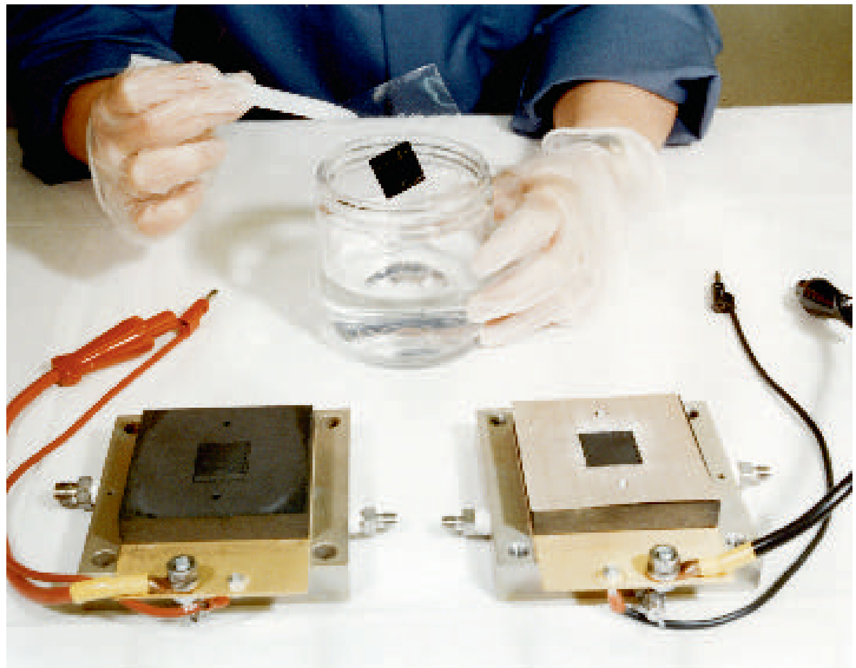
In addition, many of the materials developed by DOE for automotive and industrial technologies are applicable to aerospace. For example, ceramic turbine blades and nozzles developed for hybrid vehicles are being used in auxiliary power units for commercial jet engines.

Automotive Materials Technologies

Most of the basic materials research that is relevant to aerospace is also applicable to automotive technologies. In addition, DOE works with seven other Federal agencies and the private sector in the Partnership for a New Generation of Vehicles (PNGV). Even before the PNGV was established, DOE supported relevant R&D activities, such as development of new technologies for energy conversion, energy storage, hybrid (combined electric-and-gasoline) propulsion, and lightweight structures.

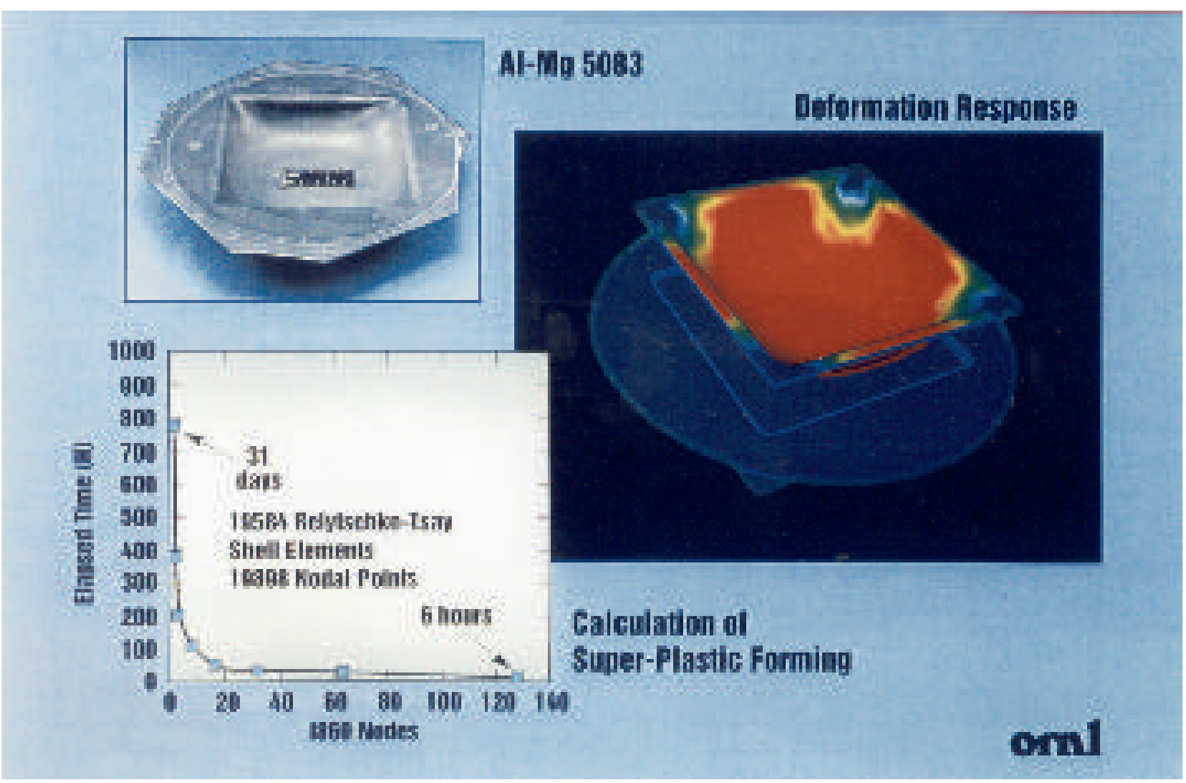
DOE has a major role in the coordination of Federal R&D addressing lightweight structural material for automobiles, working with both the PNGV and the industry-led U.S. Automotive Materials Partnership. DOE supports development of cost-effective lightweight materials and the processes needed to manufacture them reliably and competitively, through focused research by technical teams from DOE laboratories, automotive parts suppliers, private research organizations, and academia.

DOE also works with the private sector to improve power systems. These efforts include the U.S. Advanced Battery Consortium, which is pursuing development of systems that will provide future electric vehicles with significantly increased range and performance. DOE also supports development of turbine engine technology, including high-temperature-tolerant advanced ceramics.



A technician prepares to install a membrane electrode assembly into the fuel cell hardware. This polymeric membrane has a high ionic conductivity, with thin films of catalyst bonded on both its major surfaces. These films provide the active sites for the electrocatalytic reactions of hydrogen and air. The technology enables large amounts of catalyst to be used in highly robust structures, thus drastically lowering the need for precious metal catalysts.

DOE Researchers Utilize Computational Modeling to Understand Superplastic Forming of Aluminum



New Polymer Electrolytes Improve Lithium Batteries

New polymer electrolytes developed and evaluated by current and former researchers at DOE's Brookhaven National Laboratory hold promise for improving rechargeable lithium batteries for electronics applications. In this type of battery, thin plastic-polymer electrolytes conduct lithium ions between the positive and negative electrodes. The batteries are nontoxic and lightweight (unlike traditional lead-acid batteries) but require frequent charging. Previous polymer electrolytes exhibited poor conductivity, but the researchers discovered that certain new materials enhanced conduction by a factor of 400, meaning that a higher percentage of the available energy can be used, and less waste heat is produced. The team also reduced battery weight by making the positive electrodes out of lightweight plastic instead of metal oxides. The research was carried out by Brookhaven and Moltech Corp., which plans to begin production of a state-of-the-art battery soon and expects to have a work force of 200 by 1997.

Electronic Materials Technologies

Much of the DOE's basic materials research is applicable to electronics. Relevant topics include synthesis and processing of materials; properties and behavior of thin films and semiconductors, including photovoltaics; joining and interconnects; hard and wear-resistant surfaces; high-temperature superconductivity; synchrotron radiation for chip microlithography and for trace chemical analysis of microscopic samples, surface modification, and ion beam implantation; superconducting and magnetic behavior; and nanophase materials.

Environmental Materials Technologies

Many materials R&D activities have as an objective or side benefit the reduction of waste, pollution, energy use, and costs. For instance, many efforts are under way to develop new or improved materials synthesis and processing routes that minimize waste. In addition, advanced materials are being developed that will improve the efficiency and environmental acceptability of various types of power generation systems. Ceramic-matrix composites will enable development of high-temperature, low-emissions engines and turbines, while low-cost, highly selective inorganic membranes will help reduce industrial emissions and foster development of effective environmental cleanup systems.

Infrastructure Materials Technologies

DOE conducts a number of research programs that contribute to improvements in infrastructure materials. Basic research in this category addresses topics such as aqueous and galvanic corrosion prevention, welding and joining, cement and concrete science, and the mechanical behavior and failure resistance of structural materials. DOE also develops many relevant advanced materials, such as iron aluminides, which are expected to have significant infrastructure applications because they are inexpensive and combine the strength of steel with outstanding corrosion resistance.

Interaction with the Private Sector

DOE interacts with industry in many ways, including collaborative R&D, industrial use of Federal laboratories, industrial product development or commercialization based on DOE-supported research, Cooperative Research and Development Agreements (CRADAs), and licensing agreements with manufacturers that make use of DOE-patented technologies. There are literally hundreds of discrete interactions

Environmentally conscious lead-free solder developed by DOE researchers is likely to be used extensively by automobile, aircraft, and electronics manufacturers.

Lead-Free, Environmentally Safe Solder Developed

DOE scientists have discovered a lead-free solder that can form the basis for a new family of environmentally safe alternatives to traditional tin-lead solder. The new solder, which contains tin, silver, and copper, probably will find immediate uses in joining applications, such as those involved in automobile and aircraft manufacturing, as well as eventual applications in electronics and heat-exchanger manufacturing. Phase diagram studies and related microstructural analyses have been completed, and ongoing testing and development of the new solder may enable DOE to set an example of environmentally conscious manufacturing for the private sector. The eager cooperation of industrial partners and the numerous requests from other users and producers of solder suggest there is a market for the new solder, which can reduce the distribution of lead in the global environment, enhance the performance of critical solder joints, and minimize the cost of replacing tin-lead solder in manufacturing processes. The product will be marketed soon.

each year, due to the range and scope of DOE programs; the Basic Energy Sciences/Materials Sciences program alone identified over 580 industrial interactions in FY 1994. More than 490 of the department's 1,400 CRADAs are in the materials area. In addition, DOE awards hundreds of grants each year to universities for basic materials research and conducts educational programs on topics such as superconductivity.

The results of DOE-supported basic research are disseminated routinely through articles in peer-reviewed journals and presentations at scientific meetings. DOE also sponsors open conferences as a means of resolving difficult technical problems facing the entire research community. For example, in addition to supporting research on materials for energy generation systems, DOE sponsors an annual technical conference to foster advances in high-efficiency crystalline silicon for solar energy applications. The conference draws dozens of the world's top silicon experts, who come to discuss ways to limit the defect concentration in silicon ingots, and thereby increase the efficiency of the process of converting sunlight to energy.

DOE makes aggressive efforts to transfer materials developments and other advanced technologies from its own laboratories to the private sector, both to establish commercial availability and to promote U.S. industrial competitiveness. The Office of Fossil Energy alone is pursuing more than 40 technology transfer projects. Because equipment and capabilities for advanced energy research (such as that related to fusion energy) often are available only at DOE laboratories, industry depends on open access to these facilities and on dissemination of technologies developed through Federally supported R&D.

DOE also participates in many multi-agency programs that support materials R&D. For example, DOE works with the Department of Commerce on the Energy Related Inventions Program, which offers one-time support for development and commercialization of energy-related inventions, including advanced materials. DOE also collaborates with other Federal agencies and the private sector on several automotive technology development programs, including the PNGV.

Among the major DOE-run R&D programs is the Center of Excellence for the Synthesis and Processing of Advanced Materials, a distributed (or virtual) center promoting research partnerships among investigators from 12 DOE national laboratories, universities, and industry. The center seeks to integrate fundamental scientific principles with advances in materials synthesis and processing. Current projects focus on conventional and superplastic metal forming, materials joining, nanostructured materials for energy applications, microstructural engineering with polymers, tailored microstructures in hard magnets, processing for surface hardness, and mechanically reliable surface oxides for high-temperature corrosion resistance. Plans call for two additional projects focusing on high-efficiency photovoltaics and bulk metallic glasses.

DOE's Superconductivity Program for Electric Power Systems is leading a national effort to exploit the economic and energy potential of high-temperature superconducting (HTS) materials in electric power applications. The global market for superconducting products is now $1.5 billion, and experts believe it will grow rapidly, reaching $175 billion by 2020. The program focuses on superconductor synthesis, properties, currents, microstructure, and fabrication. Argonne National Laboratory received a prestigious, peer-reviewed award from R&D Magazine in 1993 for developing a novel two-powder synthesis approach to the manufacture of HTS precursors, an advance that will improve the performance of HTS wire. A series of private-public alliances has been formed through the industry-led Superconductivity Partnership Initiative, initially to establish a U.S. capability to manufacture superconducting wires, and now to provide financial assistance to industry consortia, each committed to eventual commercialization of a different product (e.g., a motor, a generator coil, underground transmission cables). The program currently sponsors more than 30 cooperative technology transfer projects. Sixteen universities are involved.

The Continuous Fiber Ceramic Composite (CFCC) program is a collaborative effort involving industry, national laboratories, academia, and other government researchers aimed at developing advanced composites to a point where industry can produce reliable, cost-effective CFCC components. These materials can increase the efficiency and reduce the environmental impact of advanced power systems. At present, seven industry-led teams are addressing industrial applications (e.g., land-based gas turbine engines, self-lubricating valve guides, boilers, combustors and heat exchangers); innovative process applications (e.g., thermomechanical processing, polymer impregnation and pyrolysis); exposure testing applications; interface development; and codes and standards.

Finally, with defense R&D budgets declining and the Administration emphasizing dual-use technologies, DOE is stepping up efforts to transfer its military technologies to civilian use and is working closely with industry to determine how the unique capabilities at Los Alamos National Laboratory can benefit the private sector. The number of alliances with individual companies and industrial consortia has increased dramatically over the last few years. Cooperative R&D projects promote industrial application of both established and emerging technologies to meet the full range of national needs, including economic competitiveness, sustainable development, and national security.

Materials R&D Base Programs

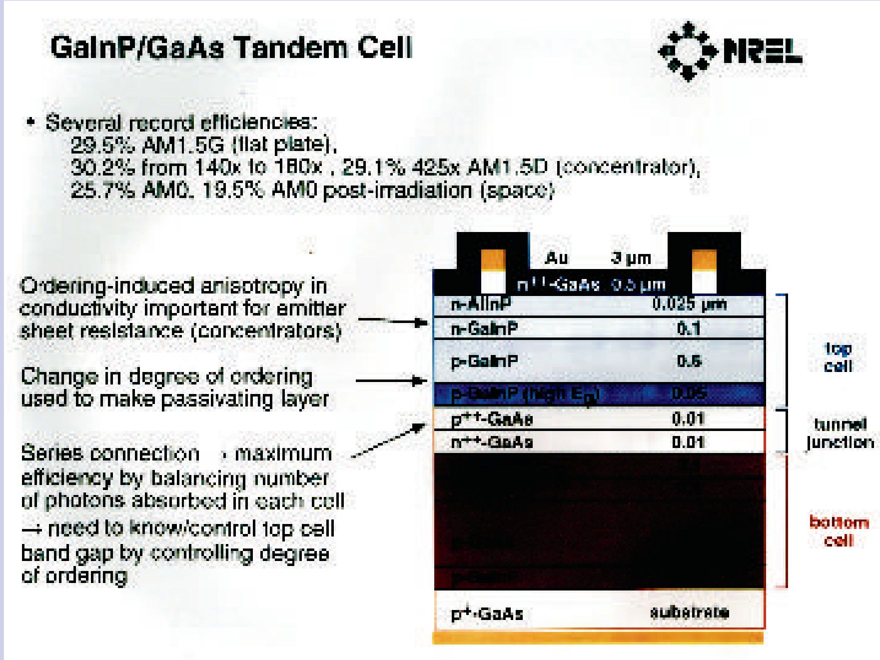
Office of Energy Research

Office of Basic Energy Sciences/Materials Sciences

Materials Sciences is the largest of four subprograms in the Office of Basic Energy Sciences. The effort currently encompasses 458 projects, including 216 at DOE Laboratories, 242 research grants (of which 233 go to universities), and 9 grants to small companies for commercialization of Federal research results.

The Materials Sciences subprogram develops scientific understanding of the synergistic relationships among synthesis, processing, structure, properties, behavior, performance, and other characteristics of materials. The emphasis is on development of the capability to discover technologically, economically, and environmentally desirable new materials and processes, and on the construction and operation of the National User Facilities and instruments needed for such research. The research contributes to development of advanced energy, automotive, environmental, and waste minimization technologies.

Basic research topics for which the Materials Sciences subprogram is either the only or a dominant supporter include aqueous, galvanic, and high-temperature gaseous corrosion prevention; welding and joining of metals to metals, metals to ceramics, and ceramics to ceramics; predictive modeling and prevention of neutron-induced irradiation damage; high-rate and superplastic forming of lightweight alloys;



Tandem Solar Cell Offers Record Conversion Efficiency

A world record photovoltaic efficiency of 30.2 percent has been achieved with a bi-level solar cell design at DOE's National Renewable Energy Laboratory, a significant improvement over the previous record of 27.6 percent. The tandem solar cell consists of carefully grown, alternating layers of gallium arsenide (GaAs) and gallium-indium phosphide (GaInP). The top cell (made of GaInP) captures the high-energy part of the sunlight and allows the unused, low-energy portion to cascade into the bottom cell (made of GaAs) for absorption. This arrangement allows a comparatively large percentage of sunlight to be converted to electricity. The advance was achieved through careful control of the GaInP material parameters, research to gain a fundamental understanding of its opto-electronic properties, and systematic analysis and optimization of device parameters. The technology is being transferred to the private sector through collaborative development efforts at Applied Solar Energy Corp.

Powerful Computers Reveal Secrets of Superplastic Forming

Powerful super-supercomputers at DOE's Oak Ridge National Laboratory are being used to model and optimize the superplastic forming of aluminum, dramatically reducing computational time and enhancing prospects for commercial use of this process, which involves bending material without breaking it. The Oak Ridge models can predict the pressurization rate that will result in optimum superplastic formability, the distribution of thickness in the formed part so that producibilty can be assessed, and the forming time (needed to estimate the cost of operation). The model was applied to analyze superplastic forming of a square oil pan (or die), considered a complex shape because of its sharp corners. The results revealed large gradients near the corner of the pan that require higher forming pressures and longer forming time than does the center of the pan. A full 128-node parallel calculation on the Oak Ridge machines was completed in six hours, whereas a workstation would require 31 days. The 128-node machine is the equivalent of about five traditional supercomputers.

metallic glasses for corrosion-resistant, wear-resistant, and low-magnetic-loss behavior and near-net-shape processing; photovoltaics for high-efficiency solar energy conversion; high-temperature structural ceramics and ceramic-matrix composites for high-speed cutting tools and fuel-efficient, low-emissions engines and turbines; and solid ceramic electrolytes for batteries and fuel cells.

Other topics dependent upon Material Sciences support include the use of synchrotron radiation for analysis of catalysts, surfaces, interfaces, and microscopic samples; electron beam microcharacterization of materials structure, microchemistry, and bond character; high-temperature superconductivity for energy generation, transmission, and storage; hard and soft magnets for low-energy-loss motors and transformers; ordered intermetallic alloys with resistance to heat, load, wear, and corrosion; nanostructured materials for energy applications; mechanical behavior and failure resistance of structural materials; NDE for early warning of impending failure and total quality manufacturing; surface modification and ion beam implantation; predictive theory and modeling for cost-effective experimental guidance and design; polymer processing; and neutron scattering for residual stress mapping.

Office of Fusion Energy

The Office of Fusion Energy is devoted to developing fusion as an environmentally attractive, commercially viable, and sustainable energy source. To accomplish its mission, OFE develops the science and technology base for fusion, conducts large-scale experiments to explore the physics and demonstrate the components of fusion technologies, and constructs and operates fusion plants. A significant component of the program involves the development and validation of the materials required for fusion systems.

Fusion involves the merging of similar nuclei, most probably the two heavy isotopes of hydrogen called deuterium and tritium, to produce a neutron and a helium atom. The kinetic energy of these particles is used to generate power. The process is the opposite of fission, or nuclear energy, which involves liberating heavy nuclei from elements such as uranium. Fusion is a promising power source because, unlike fission, it does not generate radioactive waste and, unlike oil, the raw materials are available in virtually unlimited quantities in the ocean. DOE is developing fusion as a means of eliminating U.S. reliance on imported oil. The key scientific challenge is finding ways to assure a controlled, sustained fusion reaction. It probably will be several decades before fusion energy is available.

The materials used in fusion systems must degrade slowly and predictably in an extreme environment, in which they are bombarded with neutrons. Conventional materials such as aluminum alloys and stainless steel are not suitable for these applications. For safety and environmental reasons, fusion system materials also must decay at a moderate rate -- neither too rapidly (which would affect safety factors such as system decay heat) nor too slowly (thereby complicating waste management). Materials that meet these requirements are referred to as low-activation materials.

The R&D activities focus on plasma-facing and high-heat-flux materials (e.g., beryllium, carbon composites, tungsten) that are suitable for service adjacent to the fusion plasma; structural materials (e.g., low-activation compositions of ferritic steels, vanadium alloys, and silicon carbide composites); materials for tritium breeding systems (i.e., lithium-containing ceramics); materials for diagnostic and auxiliary system components (e.g., insulating ceramics and fiber-optic systems); and superconducting magnets for plasma containment and control.

Office of Computational and Technology Research/Laboratory Technology Applications

The Energy Research Laboratory Technology Applications Program supports partnerships involving industry and DOE laboratories where efforts can be leveraged and mutual benefit can be achieved. The partnership must focus on a high-risk technology need that is defined by industry but cannot be developed by the private sector alone. The R&D efforts supported by these partnerships have resulted in new technologies being applied by industry that led to new or improved products. The materials effort includes more than 70 projects addressing topics such as novel processing and preparation techniques, wear-and corrosion-resistant materials, sensor and energy storage materials, and characterization of materials.

Office of Energy Efficiency and Renewable Energy

The Office of Energy Efficiency and Renewable Energy (EE) seeks to develop the technology needed for highly efficient use of existing energy supplies and expanded use of renewable energy sources. To support that mission, EE conducts long-term, high-risk, high-payoff R&D. A number of materials R&D projects are under way focusing on coatings and films, ceramics, solid electrolytes, elastomers and polymers, corrosion, materials characterization and transformation, superconductivity, and other topics.

Vanadium Alloy Shows Promise for Fusion Energy Systems

A new alloy that overcomes a primary barrier to development of fusion energy systems has been identified by DOE researchers and produced in large quantities by an industrial partner. Fusion, in which energy is produced by joining similar nuclei, has the potential to provide an environmentally safe energy source while eliminating U.S. dependence on foreign oil. But fusion is many years away from commercialization and many materials challenges must be overcome. The DOE fusion materials program has identified an alloy of vanadium, chromium, and titanium as a reference material capable of meeting structural requirements for fusion systems. Alloys high in vanadium (near 90 percent) appear to offer sufficient strength and ductility at operating temperatures, compatibility with liquid lithium (a source of tritium for fusion reactions), and resistance to degradation by neutron irradiation. The titanium content helps reduce structural degradation due to irradiation, offering the potential for long component lifetime. The chromium enhances resistance to creep (stretching under tension) and corrosion. In addition, chromium and titanium work together to strengthen the base vanadium. The material was produced recently as a 500-kilogram (1,100-pound) ingot by Teledyne Wah Chang Albany, the first large-scale production of an alloy high in vanadium.

New Materials Reduce Energy Use in Aluminum Production

Research sponsored by DOE has led to development of a new material that could reduce the energy used in aluminum production by an estimated 20 percent. Primary aluminum typically is produced in electrolytic cells (similar to batteries), which electrochemically reduce alumina (or bauxite) to aluminum metal. This process consumes 2-3 percent of the electricity produced in the United States each year. The new material, to be used in the cathode in place of molten aluminum, is titanium diboride, which has unique properties including the capability to decrease the voltage difference between the anode and cathode. In addition, the titanium diboride cathodes can be wetted with a thin film of aluminum, providing a stable cathodic surface and allowing the cell to operate with a narrow anode-cathode gap (meaning the device can be compact despite its high energy content). The new cathode material has the potential to lower the power consumption of the electrolytic cells by 1.5 Kilowatt hours per pound of aluminum, equivalent to approximately $0.037 per pound. Given the U.S. production capacity of 4 million metric tons (8.911 billion pounds), that amounts to an annual savings of almost $330 million. The cost of refitting a commercial cell with the new cathode is projected to be $0.024 per pound, resulting in a production cost savings of approximately $0.008 to $0.013 per pound.

Office of Industrial Technologies

The Office of Industrial Technologies (OIT) is stimulating the development and use of industrial technologies that increase energy efficiency and lower the costs of environmental protection and regulatory compliance. Through its Industries of the Future strategy, OIT is concentrating on seven industries -- petroleum refining, chemicals, pulp and paper, steel, aluminum, foundries, and glass -- that are vital to the U.S. economy yet account for 88 percent of the energy consumed in manufacturing and more than 90 percent of the wastes generated. The program is conducted in partnership with the private sector, according to R&D priorities established by industry participants.

For each of the seven industries, R&D activities focus on developing materials that will improve process efficiency (e.g., materials for sensors, catalysts and membranes, melting and refining equipment) and/or products of increased value. In addition, R&D is conducted in several cross-cutting programs to develop high-strength, continuous-fiber ceramic composites capable of operating at high temperatures, novel materials and associated processing techniques for advanced turbine systems, and corrosion- and oxidation-resistant intermetallic alloys.

As an example, several materials needs have been identified in the pulp and paper industry, for which corrosion is one of the most visible and costly issues. Wear-critical components need to be replaced or retrofitted with ultra-durable parts, inserts, or surface treatments. The industry needs improved materials to provide impact-resistant edges for chipper blades, saws, and knives; refiner materials suitable for increased rotation rates with reduced mass and enhanced fracture toughness for high-speed bearings; boiler-tube materials and surface coatings with improved resistance to hydrogen sulfide and stress-assisted corrosion; and polymer-based structural materials for vessels, piping, and valves.

Office of Transportation Technologies

The Office of Transportation Technologies (OTT) seeks to develop, in cooperation with industry, energy-efficient technologies that will enable the transportation sector to shift from near-total dependence on petroleum to alternative fuels and electricity. Additional goals are to increase the supply and availability of nonpetroleum fuels and to minimize the environmental impacts of transportation energy use. Within OTT, the Office of Transportation Materials (OTM) funds the majority of the materials development activities. Other related efforts are funded as part of vehicle systems development programs such as those addressing fuel cell electric and hybrid vehicles.

The tube shown here is a sample of continuous fiber ceramic composite (CFCC) made of silicon nitride-bonded silicon carbide in a rapid densification process developed by Textron Specialty Materials with DOE funding. The CFCC tubes are the key components of a new aluminum melting system called an immersion melter.

Within OTT, the Advanced Propulsion Division carries out research on high-temperature ceramic components and coatings to support development of automotive gas turbine propulsion systems and low-heat-rejection diesel engines for heavy-duty trucks. The Electric and Hybrid Vehicle Program supports research, development, testing, and evaluation activities focusing on technologies leading to the production of low- and zero-emission electric and hybrid vehicles. Research is under way on energy storage/conversion devices, advanced electrochemical materials, and promising battery, fuel cell, and ultracapacitor technologies.

Within OTM, the Vehicle System Materials Program concentrates on cost-effective processing and manufacture of advanced lightweight material components that, in the near term, will improve the fuel economy of current production vehicles and, over the long term, will enable the aggressive weight reductions needed in electric and hybrid vehicles.

The Propulsion System Materials Program focuses on the development of reliable, cost effective ceramics to facilitate their commercial introduction into automotive heat engines. After an aggressive 10-year effort that clearly demonstrated the feasibility of producing reliable engine components, the program is now focused on reducing the cost of ceramic components and improving their performance. Most of the research is conducted by industry. The Ceramic Technology Program is managed by the Oak Ridge National Laboratory (ORNL). This office also funds the High Temperature Materials Laboratory described in Section 4, National User Facilities.

Office of Building Technologies

The Office of Building Technologies conducts materials R&D designed to improve insulating materials and develop new ones, develop and verify analytical models useful in predicting the these characteristics gather data on thermal performance characteristics of materials, and develop methods for measuring these characteristics. In addition, technical assistance and advice on these topics is provided to industry and the public.

Office of Utility Technologies

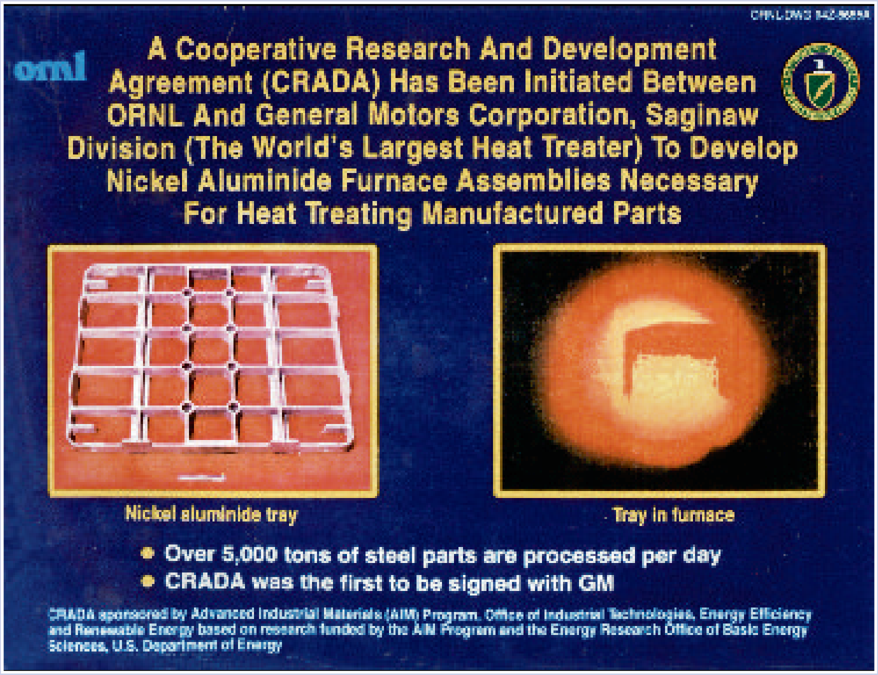
Within the Office of Utility Technologies, materials-related R&D is conducted in three divisions: Geothermal Division of the Office of Renewable Energy Conversion; Photovoltaics Division of the Office of Solar Energy Conversion; and Advanced Utility Concepts Division of the Office of Energy Management, which addresses topics such as superconductivity (a program described earlier).

The primary goal of the Geothermal Materials Program is to ensure that private-sector development of geothermal energy resources is not constrained by a lack of technologically and economically viable construction materials. To help achieve this goal, the program conducts long-term, high-risk materials R&D. For example, lightweight, environmentally benign, and chemical- and heat-resistant cements are being developed to coat the walls of geothermal wells, which are used to obtain hot water from the earth to run turbines.

The Photovoltaics Division supports numerous in-house and extramural advanced materials R&D projects. This work focuses on increasing the conversion efficiency of solar cells through new designs and new materials. Materials R&D is conducted in the following key areas: amorphous silicon thin-film materials; polycrystalline thin films, such as copper indium diselenide alloys and cadmium telluride; polycrystalline silicon thick films deposited on inexpensive substrates; high-efficiency crystalline silicon; high-efficiency gallium arsenide-based materials; improved encapsulation materials for solar cells; photo-electrochemical materials; new material characterization methods; and solid state theory.

Office of Fossil Energy

The objective of the Fossil Energy Advanced Research and Technology Development (AR&TD) Materials Program is to develop advanced generic materials that will improve the performance, durability, and efficiency of fossil energy systems while reducing their cost and environmental impact. The use of fossil fuels creates demanding conditions, so specialized materials are



Nickel aluminide trays developed with DOE support are used to process over 5,000 tons of steel parts per day.

DOE's Ductile Intermetallics Finding Many Applications

Intermetallic materials have the rare property of becoming stronger as temperature increases, but their use in energy and industrial applications has been inhibited by their brittleness at room temperature. In the early 1980s, researchers at DOE's Oak Ridge National Laboratory found that by adding boron and controlling alloy composition, they could make nickel-aluminide intermetallic alloys ductile. Since this discovery, DOE has worked with many companies to develop intermetallic alloys for multiple applications and address a host of issues in casting, welding, and related fabrication technologies. Commercial applications of nickel aluminides include industrial products and dies for the production of magnets. These dies are used to hot- press the magnets into the desired shape in air at 850˚C. The lifetime of nickel-aluminide intermetallic dies is about five or 10 times longer than that of earlier components. Nickel aluminides also have proven to be effective in furnace applications. Major users include steel mills, automotive heat-treating facilities, and preheating furnaces for near-net-shape forgings. Long-life, heat-resistant assemblies are being made from these materials, which will increase throughput and energy efficiency in parts manufacturing. Currently, iron aluminides are being evaluated for other energy-related commercial applications, such as industrial and domestic heating elements, protective weld overlays in fossil energy systems, and porous hot-gas filters in coal gasification power plants.

needed that can withstand high temperatures (thereby enabling high efficiency and throughput) and resist corrosion and erosion. The program focuses on high-temperature structural ceramic composites, structural alloys, coatings, and functional materials.

The AR&TD structural ceramics program is directed toward development of continuous fiber composites to overcome the lack of fracture toughness in conventional ceramics. The primary materials of interest are silicon carbide composites. Potential applications include heat exchangers; burners; particulate filters; heat engines; and components and equipment for coal gasification, combustion, and liquefaction, and gas stream clean-up. Technologies under development include a matrix-forming process involving chemical vapor deposition that produces dense composites quickly and in thick parts; a process for production of pure, high-quality, high-strength, single-crystal silicon carbide fibrils; ceramic joining methods; NDE methods, including three-dimensional (3-D) X-ray computed tomography, nuclear magnetic resonance and ultrasound methods; environmental testing; and development of suitable fiber-matrix interface coatings and ceramic-oxide-type coatings for exterior surfaces of silicon carbide composites.

Alloy research addresses advanced austenitic (steel) alloys, iron aluminides, and chromium-niobium intermetallics and coatings. Advanced austenitic alloys are needed to enable temperature and pressure increases in pulverized coal power plants and thereby increase efficiency and reduce costs and emissions. The materials must have high creep resistance (i.e., they must resist stretching under tension). The advanced alloys, modifications of commercial stainless steels, are made using a new concept involving ultra-fine precipitate microalloying, a special heat treatment and cold working process. The resulting creep resistance is orders of magnitude greater than that of the commercial counterpart materials.

Iron aluminides are being developed that will tolerate the extreme environments of coal gasification, combustion, and liquefaction systems, which cause rapid corrosion of current alloys. The iron aluminide alloys have greater resistance to corrosion and sulfidation (reaction to sulfur) than does any other alloy, and costs are expected to be relatively low. The principal problem to be overcome is the materials' low ductility at low temperatures. Research also is under way to determine the feasibility of developing an ultra-high-temperature chromium-niobium intermetallic alloy that could replace or complement ceramics in applications such as heat exchangers and heat engines operating at temperatures up to 1250°C.

In another program, low-cost, versatile coatings are being developed that will protect against corrosion and erosion in fossil energy environments at various temperatures and do not spall (flake off in bits). Two coating processes are being developed. One is pack cementation, which produces chromium-aluminum or chromium-silicon diffusion coatings for small or large parts. The other is the electrospark process, which can bond almost any electrically conductive material in single or multiple complex coatings to substrate metals. Research also is under way to expand understanding of the corrosion of metals in fossil energy systems. The resulting database will enable the development of improved alloys and coatings.

Various functional materials are under development. Highly selective, low-cost inorganic membranes are being developed for high-temperature (600°C) product separation systems, such as those that remove hydrogen in coal gasification systems or remove acid gases (hydrogen sulfide and nitrogen and sulfur oxides) from coal conversion and combustion systems. This effort is made possible by knowledge of gaseous diffusion membrane technology developed over the years at ORNL. Widespread commercial application of these membranes is anticipated.

Hydrous metal oxide catalyst supports are being developed to improve the reactivity and selectivity of catalysts and reduce the cost and improve the environmental performance of coal-to-liquid-fuel conversion systems.

Research also is under way on materials for solid-state electrolyte systems that will provide for highly efficient, economical, and environmentally clean use of fossil fuels. New synthesis, processing, and fabrication methods are being developed for materials used in electrodes, bipolar interconnects, ionic membranes, and catalysts. An example of such a material is uniform, nanosized, oxide compound ceramic powder. Potential applications for these functional electrolyte materials include solid-oxide fuel cells, hydrogen and oxygen production systems, gas stream separation and clean-up systems, sensors, and new electrochemical processes.

Other functional material developments include ceramic composite and iron aluminide filters for removal of particulates in advanced gas turbine-based power systems and carbon composite molecular sieves for gas separations.

Office of Nuclear Energy

Office of Space and Defense Power Systems

The Office of Space and Defense Power Systems is responsible for the design, development, production, and safety of reactor and radioisotope nuclear power systems for space and terrestrial applications. These systems are used by the National Aeronautics and Space Administration and the Department of Defense. Since the recent termination of a major space reactor program, a significant effort has been mounted to transfer materials and component technologies to other agencies and industry for development of commercial applications.

The R&D in radioisotope power system programs focuses on advanced power conversion systems such as thermophotovoltaics and Stirling dynamic systems. The research portfolio includes thermoelectric materials and devices for energy conversion, high-temperature heat source materials, materials systems compatibility, and safety-related materials characterization. Past successes with thermoelectric materials and devices and high-temperature metal alloys and graphite-carbon materials for heat sources enabled the development of a series of ultra-reliable, long-life radioisotope thermoelectric generators (RTGs). These compact, low-power systems employ a fission process, in which charged particles and neutrons are emitted that can be used as energy sources. The RTG system has been an enabling technology for deep-space planetary exploration programs, such as Voyager (which went to Mars, Jupiter, Saturn, and beyond); Galileo (which went to Jupiter); Ulysses (which went to the polar regions of the Sun); and the upcoming launch of the Cassini mission to Saturn.

Office of Defense Programs

Materials research efforts in the Office of Defense Programs are focused on nuclear weapons. However, most of these efforts are broadly applicable to conventional defense and civilian technologies. In recent years, the office has stepped up efforts to collaborate with the private sector on research and open national laboratories to civilian users. The program addresses virtually all materials in the periodic table, from hydrogen to the actinides. Materials R&D activities are concentrated in three general areas: energy and environmental technologies, national security (nuclear weapons/nuclear materials), and core research.

Work on an ultra-high vacuum diffusion bonding machine permits preparation of engineered interfaces with atomic precision and cleanliness, enabling researchers to study, understand, and predict the behavior of interfaces (such as welds) in real engineering systems. This capability has been combined with X-ray microtomography to permit in-situ characterization of failure mechanisms in molecular bonds, with resolution of at least five microns.

Materials R&D in the area of microelectronics and opto-electronics addresses sub-micron X-ray lithography, thin-film materials for nonvolatile memories and electronic packages, interaction of optical and electronic functions, compound semiconductors for ultra-low power requirements, radiation-hardened electronic structures, advanced metallization for ultra-high-density integrated circuits, micro-micromachining, substrates with ultra-low dielectric constants, optical interconnects, conformal coatings, and 3-D electronic structures.

Computer models are used to design materials with tailored electronic, optical, chemical, thermal, and mechanical properties. Materials processes are being modeled to provide computer simulation during the design phase of component manufacturing. Significant efforts are under way to model advanced composites, including structural composites; hybrid materials; advanced matrix materials; multi-axis fiber winding; X-ray tomography and other nondestructive testing methods; and low-cost fabrication methods.

Work on environmentally compatible materials and processing includes development of polymeric sensors for chemical processing, electronic manufacturing, waste stream monitoring, and environmental degradation detection; nontoxic materials and processes, including lead-free and fluxless solders, batteries and power supplies, printed wiring boards, machining, plating, and surface cleaning; and new processes for waste minimization, including investment casting and die designs.

Projects aimed at enhancing materials reliability, lifetime, and compatibility include development of service-life predictive models, advanced corrosion protection, in-situ corrosion monitors and sensors, and compatibility models and data for advanced materials.

One laboratory makes components out of radioactive and explosive materials, which, due to handling hazards that make research difficult, are poorly understood in comparison to most other materials. The laboratory has commissioned a new uranium foundry and a spin-forming capability to fabricate uranium parts in a way that reduces costs, waste, and footprint (i.e., trail). Researchers are studying the basic deformation mechanisms of uranium alloys in an effort to improve modeling of the component formation processes. Twin deformation (a mirror-image process occurring in crystals) has been characterized with electron microscopy, but the dislocation motion in this unusual material has yet to be defined. A second major effort focuses on precision casting of plutonium components.

Activities in high explosives range from research on the basic mechanisms associated with explosive sensitivity to development of environmentally sound methods for explosive destruction. Significant advances have been made in understanding explosive sensitivity through models calculated using molecular dynamic theory. Theoretical methods also are being used to predict and characterize novel high-energy-density materials. In addition, new destruction techniques are being sought to replace the open burning or open detonation of waste and scrap explosive. A small prototype unit has been built that reacts the explosive with a molten inorganic salt and converts it to innocuous gaseous products.

Other materials modeling activities range from investigations of electronic structure and molecular dynamic calculations to finite element modeling and the development of thermal-chemical models of the response of high explosives. This approach has improved understanding of the mechanisms associated with the effects of molten plutonium on refractory metals. In one project, theoretical analyses that suggest novel uses and interpretations of data are providing for a powerful new diagnostic tool, which can be used to "see" the underlying electronic structure that determines the fundamental physical and chemical properties of solids. Finite element modeling is applied to expand understanding of the behavior of explosives and other materials subjected to various mechanical and thermal environments.

Research is under way that will lead to improved performance in microelectronic devices for industrial and consumer electronics. Atomic-level materials theory and modeling software are being used to study etching, passivation, growth of thin films, and other processes. The laboratory is working with other agencies and the private sector to develop a set of computational tools that will enable routine study of larger molecular systems (containing hundreds of thousands of atoms) for longer time periods than is currently possible. These tools will be of special benefit to the pharmaceutical and polymer industries.

Nanostructured materials, in multilayer and aerogel forms, are becoming increasingly important due to their unique properties. The capability to prepare dielectric layers with carefully controlled, reproducible atomic structure and composition has been developed. This advance opens a new realm of applications with high-energy-density multilayer capacitors (neutral elements that separate charged components and store energy).

Novel crystalline materials are being synthesized using high-shock pressures produced with a projectile launched from special light-gas gun. Using this approach, researchers have compacted various ceramic and magnetic powders, altered superconducting-critical-current densities with shock-induced defects, produced unusual glass by shocking crystalline quartz, and performed impact experiments to help design the containment fixture for a high-velocity flywheel to by used in future automobiles.

DOE's New Ultrasound Method Can Characterize Many Materials

DOE scientists have developed a simple and inexpensive new technology, resonant ultrasound spectroscopy, that can be used in nondestructive evaluation (NDE) of many materials. The technology takes advantage of a fundamental feature of solids, including metals, ceramics, plastics, and composites, which can be made to resonate mechanically by vibrating them at specific frequencies. The resulting spectrum of mechanical resonances contains a wealth of information about the samples' elastic properties, internal friction, structural integrity, and shape. These data can be collected to learn about the basic characteristics of a material or to determine whether it has been degraded or damaged in some way. Resonant ultrasound spectroscopy is not limited by the material's size or shape; both very small (less than 1 millimeter in diameter) single crystals of new materials and very large shapes, such as highway bridges, have been tested successfully. The test is quick, simple, and inexpensive enough to carry out on production and assembly lines or in the field. Honored by a 1991 award from R&D Magazine and a 1993 Federal Laboratory Consortium Award for Excellence in Technology Transfer, the technology has been licensed to Quatro Corp., which will use it to develop and manufacture NDE systems.

Research on new laser glasses is under way for the National Ignition Facility, which is to be used for fusion research. The facility requires about 4,000 laser glass plates, each with a volume of 13 liters, a size greater than ever produced before. In addition to working with private companies to develop an advanced melting process that would enable production of all the laser slabs in about three years, the laboratory has undertaken a major R&D effort to understand the relationships of the physical, chemical, and spectroscopic properties of laser glasses to glass structure and composition. Although there is a wealth of information about structure-property relationships for silicate glasses, information about phosphate glasses is relatively sparse. Over the past several years, a database has been developed of several hundred different meta-phosphate glass compositions, their neodymium spectroscopic measurements, and their laser and optical properties.

Researchers work with a variety of hazardous materials, such as plutonium, explosives, tritium, beryllium, thallium, silanes, boranes, volatile organic compounds, and depleted and enriched uranium. Synthesis and processing capabilities extend from traditional metallurgical and ceramic processing to thin-film coatings, energetic materials, composites, hydrogen storage, polymeric membranes, acid sensors, and superconducting tapes.

Current nuclear weapons programs address the need to understand aging effects in a static nuclear stockpile and the need for a residual manufacturing capability (for replacement components and safety enhancements) in a radically downsized nuclear weapons complex. Activities range from fabrication of components to development of new materials for enhancing safety or improving understanding of physics issues.

To contain hazardous materials such as those used in weapons, high-temperature liquid-metal-compatible pressure vessels, damage-resistant coatings, diffusion-bonded laminate composites, and damage-tolerant ceramic-matrix composites are being developed along with associated fabrication technologies. The ultimate goal is to establish a prototype state-of-the-art manufacturing facility for the future.

The weapons program is a leader in rapid prototyping of metal components by direct laser fusing of metal powders and is demonstrating future welding technology with fiber-optic beam transmission and multiple-station capabilities. "Intelligent" processing research incorporating real-time diagnostics and control is an integral part of this capability. Similar improvements in fabrication capability are being achieved in the areas of high explosives, plutonium, uranium reprocessing and purification, uranium metallurgy, and lithium salt fabrication. Work also is under way on near-net-shape processing, which reduces costs and waste, and elimination of hazardous materials within processing schemes. Technology has been developed for manufacturing spherical beryllium powders, for example, enabling demonstrations of near-net-shape component manufacture and plasma-spray coatings.

A Center for Materials Processing Modeling has been formed to bring together several disciplines. Predictive design methodologies are being developed that will make use of above-ground non-nuclear test techniques for experimental verifications that can be extrapolated to nuclear conditions. Materials R&D to support fabrication of targets (fuel pellets) for laser-driven fusion energy systems has grown to include efforts to support explosive-driven fusion and electromagnetic pulsed-power generation. Weapons physics designers have initiated scalable experiments to sharpen the design of underground testing and supplement experimental data that formerly could be obtained only through nuclear testing.

A Target Fabrication Facility has been re-oriented to handle evolving manufacturing challenges related to new materials and component geometries. Research issues in the manufacture of micro-engineered targets include development of coating processes involving metallic composites, polymer synthesis to provide organic materials with improved machinability and engineered physical properties, and development of foams with densities approaching that of air yet predictable shrinkage and composition. This class of materials offers significant potential for minimizing radar signatures of structures.

Processing and characterization of composites has been a major emphasis for decades. The development of molybdenum silicate composites, for instance, has been one of the most successful materials programs, with potential applications in gas nozzles and heat exchangers. Work continues on molybdenum silicate composites to improve both the high-temperature strength and the low-temperature toughness. Collaborations are underway with aircraft engine manufacturers to develop engineered nanolayers for thermal barrier coatings. An ion gun has been developed for high-rate film deposition with a potential for producing chemically modulated nanolayers. The role of interfaces in determining mechanical and physical properties is being studied both experimentally and theoretically.

Office of Environmental Management

To support safe and cost-effective environmental restoration and waste management operations, the Office of Environmental Management sponsors development, demonstration, testing, and evaluation of new and improved materials. Advanced materials are needed for remediation system structural components (e.g., corrosion-resistant refractory materials are needed for thermal treatment systems, such as glass melters and plasma arc systems; sensors (durable, reversible, and selective thin films are used in chemical sensors, and microbe-compatible materials in biosensors); containment systems for durable, stable final waste forms (materials of interest include improved glasses, encapsulants, impregnants for soil excavation, and strippable coatings for decontamination); separation systems (e.g., improved ceramics are needed for high-temperature filters); improved catalysts; and recycling, to transform materials into components for applications such as canisters for storing or disposing nuclear materials.

Most of the materials R&D is conducted in four focus areas addressing key environmental management problems: tanks, mixed waste, decontamination, and decommissioning. Some additional materials R&D is carried out within the spent nuclear fuels program and technology adaptation efforts integrated into other Environmental Management programs.

Major Research Laboratories and Centers of Excellence

Ames Laboratory
Iowa State University
Ames, IA 50011

Argonne National Laboratory
9700 S. Cass Ave.
Argonne, IL 60439

Brookhaven National Laboratory
Upton, NY 11973

Idaho National Engineering Laboratory
Idaho Laboratory Facility 215
P.O. Box 1625
Idaho Falls, ID 83415

University of Illinois Frederick Seitz Materials Research Laboratory
104 South Goodwin Ave.
Urbana, IL 61801

Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Lawrence Livermore National Laboratory
P.O. Box 808
Livermore, CA 94550

Los Alamos National Laboratory
P.O. Box 1663
Los Alamos, NM 87545

National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, TN 37831

Pacific Northwest Laboratory
P.O. Box 999
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Sandia National Laboratories
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Office of Computational and Technology Research/Laboratory Technology Applications

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National User Facilities

Contacts for National User Facilities are listed in Chapter 4, National User Facilities.

Annual Reports are available by contacting:

Report Title: Materials Sciences Programs (No. DOE/ER-0648)

Report Title: Energy Materials Coordinating Committee Annual Technical Report (No. DOE/ER-0625)

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Department of The Interior

DOI Primary Organizational Units Sponsoring R&D Programs in Materials Science and Technology:

United States Bureau of Mines (USBM)

Materials Research Partnership Center (MRPC)

Overview of Materials R&D Activities

The Department of the Interior (DOI) manages most of our nationally-owned public lands and natural resources. Through its science bureaus, the U.S. Bureau of Mines (USBM)[14] the U.S. Geological Survey (USGS), and the National Biological Service (NBS), DOI conducts research into earth processes, systems, and hazards, resource conservation, the prevention of environmental harm, biological and geological inventory, monitoring and assessment, and environmental remediation to provide the scientific basis for natural and cultural resource policy and management decisions. DOI materials research, conducted principally by USBM, focuses on resource conservation and the prevention of environmental harm through the development of long service-life materials; recycling and waste minimization technology; and low cost, environmentally benign metals processing technology. The other research areas such as resource assessment, mineral extraction, and environmental remediation, while clearly materials-related, are not included in this program. Instead, they are reported by the NSTC Committee on Environmental and Natural Resources (CENR).

The USBM materials R&D is conducted at the Materials Research Partnerships Center (MRPC). The MRPC has been set up to emphasize partnerships in which costs and work are shared with industry or other Federal agencies. In general, the MRPC addresses problems associated with the performance of engineering materials in manufacturing plants, structures, vehicles, and equipment, with the overall aim of increasing the efficiency of material use. Efforts to improve casting technology have resulting in many advances in material performance. Staff expertise is concentrated in the areas of wear and corrosion, which affect diverse industries ranging from automobiles to construction. Additional expertise in chemical analysis, pyrometallurgy, and electrometallurgy assists in the identification, sorting, separation, and recovery processes needed to investigate the recycling of advanced materials and alloys.

As part of its mission, the MRPC provides technical support in materials technologies to other USBM centers, which focus on pollution prevention and control, environmental remediation, and health and safety. However, extractive metallurgy, environmental remediation, and health and safety R&D are not included in this program.

Materials R&D Related to National Priorities

Automotive Materials Technologies

Along with other Federal agencies and industry, USBM is participating in the Partnership for a New Generation of Vehicles (PNGV). The USBM is focusing on lightweight materials that could help improve the fuel economy of vehicles. Researchers are considering not only performance characteristics but also the full life-cycle costs of significantly expanded use of several of these materials. Efforts are under way to reduce the cost of titanium mill products (so that these materials will be economical for widespread automotive applications), improve production technology for magnesium, enhance the durability of lightweight metals and composites, and resolve recycling issues.

Environmental Materials Technologies

The USBM long has been concerned with environmental problems associated with materials and materials processing. Topics selected for collaborative R&D by the MRPC support its mission of resource conservation through development of recycling and waste minimization technologies. For example, one project is aimed at developing refractory bricks that are recyclable. Efforts also are under way to perfect high-temperature processing methods for converting municipal wastes into inert glassy materials that will not cause environmental damage around landfills.

[14] Pending legislation in late 1995 proposes that the Bureau of Mines be disestablished as an organizational unit of the Department of Interior. The legislation further recommends that many of its essential programs and activities be transferred to other units within DOI or other government agencies. For further information contact the Bureau of Reclamation at the address listed at the end of this section.

Infrastructure Materials Technologies

Several materials R&D projects have infrastructure applications. In cooperation with the State of Oregon and private companies, the USBM is investigating the deterioration of structures in coastal environments. The objective is to develop a capability to predict corrosion of metal structures and reinforced concrete based on knowledge of atmospheric conditions at a particular site. Although the research focuses on near-ocean locations, the results also should be useful in minimizing road damage during application of salt for de-icing of roads.

In another project, the USBM is working with a private company to develop sensors that indicate the maximum strain to which a structural member has been exposed. The sensors, based on transformation-induced plasticity (TRIP) steels developed by USBM, are being considered as the basis for a low-cost system that could warn of damage to and impending failure of structures such as bridges. Made of iron, chromium, and nickel when used for monitoring applications (manganese and carbon are added when the material is used in structural members), TRIP steels transform from a nonmagnetic to a ferromagnetic state at particular stress levels. These alloys can be customized for different applications.

Model Predicts 60-Year Life For New Roof at Monticello

The roof at Monticello was repaired recently with tin-plated stainless steel shingles to replicate the original appearance of President Thomas Jefferson's home in Charlottesville, Virginia. The projected life of the 24-micrometer-thick tin plate was estimated at more than 60 years. The thickness needed and the impact of atmospheric factors on the tin plate were estimated using a corrosion model developed several years ago by USBM and the Environmental Protection Agency. The model, originally intended for use in measuring the effects of acid rain, has wide application for assessing other environmental impacts on metals, interpreting corrosion performance, and predicting corrosion damage. The model permits prediction of structural life and assists in the design process. Researchers previously relied on guesswork.

Interaction With the Private Sector

In the past, USBM materials R&D primarily addressed DOI and Administration priorities through Federally funded research addressing the synthesis, processing, and performance of metals, alloys, and other materials. The results then were targeted for transfer to the private sector. By contrast, the current emphasis on partnerships demands the early involvement of customers, an arrangement that helps the MRPC apply in-house capabilities in the most cost-effective manner. Potential partners are involved in all stages of R&D planning, and the program is driven primarily by partners' needs.

The past several years have seen an increase in cost-shared interactions with the private sector, as well as with other Federal and state agencies. In FY 1994, Cooperative Research And Development Agreements and Memoranda of Understanding represented 15 percent of MRPC funding (counting both cash and in-kind contributions), up from a 10 percent share for non-USBM appropriation sources in FY 1993. Outside sources are expected to account for about 20 percent of the center's funding in FY 1995. The ultimate goal is for MRPC programs to be fully cost shared.

In the first half of FY 1995, MRPC entered into 23 partnership agreements with companies, trade associations, and industrial consortia. The center also expanded access to its unique materials R&D facilities by creating two post-doctoral and seven graduate or undergraduate positions in FY 1994. In addition, MRPC has several teacher training programs in science and mathematics underway. The quality of the work carried out by MRPC researchers is evidenced by, among other things, a number of recent awards, including the Jacquet-Lucas Award for analytical electron microscopy.

Materials R&D Base Programs

Infrastructure

Corrosion damage to the Nation's infrastructure directly and indirectly cost the economy more than $100 billion in 1989. With repair costs for existing substandard structures estimated at more than $1 trillion ($90 billion for deficient bridges alone), many efforts are under way at USBM and elsewhere to develop or improve methods for structural preservation. At USBM, the current emphasis is on technologies for bridges, which have been identified as a critical national problem.

Various protection systems, such as coatings, are in use to prevent corrosion. Other types of systems can detect corrosion or warn of impending structural defects and failure. The current fundamental knowledge base is insufficient to provide for accurate prediction of how well, or for how long, a particular protection method will work. The USBM is carrying out research that will expand fundamental understanding and help estimate the effectiveness and longevity of these systems. Research partners include the Oregon Department of Transportation, an aluminum company, and coastal utilities.

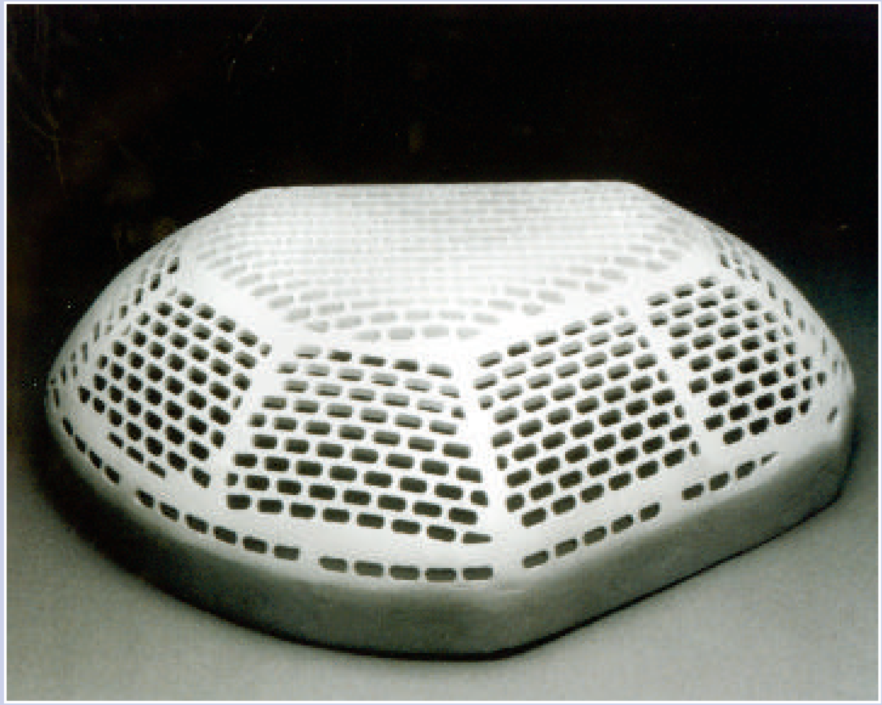
The study of corrosion inhibition and protection measures for large-scale structures containing reinforced concrete will yield important information about sacrificial anodic coatings and cathodic protection systems. For example, the study of zinc-coated concrete in the laboratory and at field locations can determine how long these coatings last in particular atmospheric conditions and their effectiveness as a function of time. Evaluation of microclimates in the vicinity of existing bridges can suggest the best location for future replacement bridges.

For monitoring of bridges and underground mine shafts, "smart" materials such as TRIP steels can be attached to provide quick, simple, and inexpensive warnings when structural members approach failure. The higher the strain, the greater the linear change in the TRIP steel's magnetic properties. These steels can be engineered for specific applications by matching the tensile and magnetic response to the structural needs. The use of these steels in bridge and mine monitors will help alert maintenance crews of the need for repair before catastrophic failure occurs.

The USBM is developing the monitor materials and hardware, and a sensor company is developing the electronics for both active and passive monitoring systems. The Georgia Department of Transportation has offered engineering services and traffic control for the monitoring of up to nine bridges on Interstate 95, and further support is being sought from other states along the I-95 corridor between Florida and Maine.

Processing of Lightweight Materials

If the goals for the PNGV are to be met, then new materials and associated processes will be required. Life-cycle costs of these new materials, especially environmental and recycling costs, will be a major factor in materials selection. Candidate lightweight materials for automobile components include titanium, magnesium, aluminum, and plastics. Each presents problems if produced on the scale required by the automotive industry. The PNGV-related problems addressed by USBM include the lack of affordable titanium for use by the automotive industry, the dearth of property data



Low-Cost Titanium Developed for Military Applications

Building on its development of new casting technology that eliminates the need for costly machining, USBM has demonstrated the technical feasibility of producing armor and other military components from low-cost titanium alloys. Titanium offers significant benefits over other armor materials, including steel, which is not as strong, and depleted uranium, which is heavier and potentially hazardous. Until recently, the cost of titanium armor was prohibitive. Under a cooperative program with the Department of Defense, USBM fabricated and arranged ballistic testing for prototype armor made from titanium alloys, which were developed through a public-private partnership. Hatch covers (see photo) and other applications of this new materials technology are used on the Bradley Fighting Vehicle and proposed for the M-1A2 Abrams tank, the M-113 armored personnel carrier, and the HUMVEE utility vehicle. In comparison to conventional aerospace-grade titanium alloys, the new materials will save more than $2.5 million in FY 1996, $3 million in FY 1997, and potentially $40 million over the next five years, depending on whether low-cost titanium is accepted for use on the Abrams tank.

on new magnesium alloys, and the need for increased stiffness and wear resistance in aluminum alloys or composites.

The automotive industry has indicated that it probably would use titanium in engines if processing costs for near-net-shape components made of this material could be reduced from about $10 to $5 per pound. (Aerospace-grade titanium is much more expensive.) Potential applications include intake valves, valve springs and keepers, and connecting rods. Titanium also might be used in suspension springs, enabling reductions in diameter and length that are not possible with steel, which is heavier and has a lower modulus of elasticity. The USBM is developing and evaluating continuous production of near-net-shape titanium on a pilot scale, a process expected to cost less than conventional batch production. The capability to carry out the new process already has been developed, forming the foundation for a strong effort to develop new low-cost methods for processing titanium, titanium alloys, and composites.

Capacitor discharge welding can be used to join dissimilar metals without fluxes and without the typical problems involving heat-affected zone failures.

A separate effort is under way to gather baseline engineering data for new magnesium alloys, which are being developed in response to the demand for lightweight automobiles. Researchers are evaluating, for example, material behavior under high rates of stress and strain, and mechanical, corrosion, wear, and fracture properties. Aluminum alloys are also under study. The strength, stiffness, and wear resistance of these alloys can be increased by the addition of hard particles such as silicon carbide. On a pioneering basis, the MRPC built and tested a small centrifugal casting unit for producing aluminum composite camshafts.

Environmental Impact of Materials Processing Technology

U.S. industries continue to generate hazardous waste that causes environmental damage. Reduction or elimination of this waste stream is essential, both to enable these industries to become more competitive in a worldwide market, and to improve the quality of life for all Americans by removing toxins from the environment. Because of its expertise in metals processing, the USBM is equipped to address several aspects of this issue and is pursuing three projects in cooperation with the Environmental Protection Agency and a number of private companies.

The USBM is making near-term contributions to the following projects: development of flux-free joining technology, to reduce the volume of fluoride-containing fluxes in waste; development and demonstration of chloride-free processes for recycling aluminum-magnesium alloys, which are used in cans and other products; and development of unique pouring systems that will increase productivity and reduce energy consumption in aluminum casting operations.

Wire joined to stubs by capacitor discharge welding, which minimizes heat-affected zones and does not require the use of dangerous fluoride-containing fluxes.

Major Laboratories and Centers of Excellence

The principal center for USBM materials research is the Materials Research Partnerships Center, Albany, Oregon.

Academic and industrial researchers are encouraged to use MRPC facilities, which offer varied materials processing equipment and expertise. For example, the center has the capability to cast a wide variety of metals and alloys, from gram quantities to hundreds of pounds. It also has unique, well-instrumented, pilot-scale electric arc and cupola furnaces. The staff has expertise in the many different forms of corrosion, and corrosion and corrosion-wear testing methods are available that provide laboratory and field data quickly and cost effectively. The MRPC staff also has broad expertise in fracture and wear, and fracture and wear testing methods are available.

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Department of Transportation

DOT Primary Organizational Units Sponsoring R&D Programs in Materials Science and Technology:

Federal Aviation Administration (FAA)

Federal Highway Administration (FHA)

Federal Highway Traffic Safety Administration (NHTSA)

U.S. Coast Guard (USCG)

Maritime Administration (MARAD)

Federal Railroad Administration (FRA)

Federal Transit Administration (FTA)

Research and Special Programs Administration (RSPA)

Office of Hazardous Materials Transportation
Office of Pipeline Safety

Overview of Materials R&D Activities

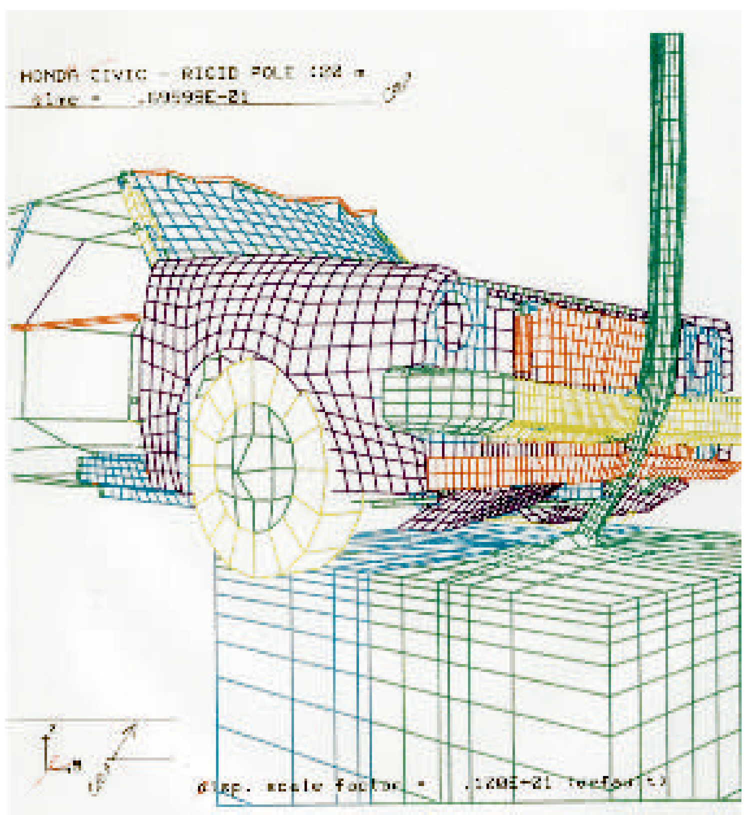
The primary mission of the Department of Transportation (DOT) is to ensure safety, mobility, access, and efficiency in the movement of people and goods within the U.S. transportation system, while preserving the environment, advancing technology, and promoting economic growth. DOT encompasses 10 modal administrations with safety and regulatory jurisdiction over highway planning, development, and construction; highway traffic safety; urban mass transit; railroads; national air space operation, airports planning, and aviation safety and security; the safety of waterways, ports, and commercial shipping; and the safety of oil and gas pipelines as well as hazardous materials transportation.

Traditionally, operating and research support programs have been carried out primarily by transportation mode (e.g., air, marine, rail) within the operating administrations. However, since the enactment of the Clean Air Act Amendments of 1990 and the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, R&D activities increasingly have been integrated and coordinated across transportation modes.

Further integration of R&D program planning and implementation would result from DOT consolidation and streamlining, as now proposed, into three administrations (aviation, intermodal, and marine). DOT's materials R&D programs would be strengthened by this move from mode-specific projects and applications toward synergistic, cross-modal technology transfer, and by improvements in internal coordination and communication effected through DOT's Research and Technology Coordinating Committee (RTCC). An RTCC Materials R&D Subcommittee is supporting DOT strategic goals targeting infrastructure renewal and expanded application of advanced materials. The overall objective is to enable early technology deployment so as to enhance safety, operational efficiency, and environmental compatibility of transportation systems.

The majority of DOT's materials R&D is carried out by the Federal Aviation Administration (FAA), Federal Highway Administration (FHWA), and Research and Special Projects Administration (RSPA), while other modal administrations pursue some materials R&D to support their missions. The emphasis is on applied research and demonstration programs; therefore, rather than materials development, DOT's primary activities involve characterization and evaluation of application-oriented materials, and development of standards for safety in performance, certification, and regulatory enforcement. Evaluations of the safety and operability of new transportation technologies often exploit and rely on basic and applied research conducted by other Federal departments, organizations, and industry.

R&D projects are conducted by intramural research centers, private sector contractors, and university research consortia and centers of excellence. The Transportation Research Board



This schematic illustrates the FHWA's use of the DYNA-3D (developed by the Department of Energy) finite element analysis combined with real crash tests. This sequence illustrates a simulation of a car colliding with a sign post, using crash parameters and roadside hardware design and materials characteristics from FHWA's Federal Outdoor Impact Laboratory.

Lightweight, high-strength, large-capacity composite transportation container developed by Structural Composites Industries for hazardous materials.

(TRB) of the National Academy of Sciences (NAS), in partnership with the states and industry trade associations, also provides research management support to DOT modes. The modal administrations cooperate on a number of materials R&D efforts, such as the TRB-managed Innovations Deserving Exploratory Analysis program, which includes specific thrusts in advanced materials, composites, and structural uses for recycled materials. DOT is always on the lookout for promising new technologies in any field that might be applicable to transportation vehicles and infrastructure.

The FAA carries out materials R&D to support its efforts to enhance aircraft safety, advance airport technology (including pavements and security systems), and improve the operational safety and efficiency of air transportation. Materials of interest include improved runway pavements, new fire-safe materials for aircraft cabins, engine and structural materials (for safety evaluation purposes only), and reliable electronic materials for radar and communications systems.

The FHWA's materials R&D targets highly durable and environmentally benign pavements and structures; corrosion-resistant coatings; nontoxic de-icing materials; nondestructive testing, evaluation, and inspection (NDT/NDE/NDI) methods for monitoring the structural integrity and safety of highways and bridges; and advanced materials and practices for infrastructure renewal. Materials under study include high-strength concretes, composites, plastics, adhesives, and recycled wastes.

RSPA manages several DOT programs that support extramural R&D on advanced materials and operates a research and technology center serving the entire department and other Federal agencies. In addition, RSPA supports R&D focusing on lightweight, high-strength, corrosion-proof materials used in containers for hazardous substances; corrosion-resistant materials and techniques (e.g., plastic piping, coatings, effective cathodic protection) for gas pipelines; and NDI methods for examining containers and pipelines.

Additional mission-support materials R&D is carried out by the National Highway Traffic Safety Administration (NHTSA), the Coast Guard (USCG), Maritime Administration (MARAD), and Federal Railroad Administration (FRA).

DOT participates in several NSTC committees including CCIT and MatTec. The NSTC's strategic plans identify the transportation physical infrastructure as a national priority for FY 1996; the major materials-related R&D thrusts include improved diagnostics, combining

To meet crashworthiness standards and ensure operational safety, the FAA R&D program tests a variety of aircraft types, such as the all-composite Beech Starship aircraft in the photo.

Polymers to be Used in Fire-Resistant Aircraft Interiors

Research on advanced polymers is the linchpin of an FAA program intended to develop and demonstrate a prototype fire-resistant aircraft cabin interior by 1999. This broad R&D program, which involves several Federal agencies, private manufacturers, and academic institutions, combines advances in materials fire safety with improvements in fire management and safety systems (e.g., smoke detectors, spray systems). High-temperature thermoplastics, based on tailored polymers with highly cross-linked molecular structures that do not support combustion, and fire-resistant foams that will replace urethane seat cushions are being developed and tested by FAA researchers, in close cooperation with researchers from the Departments of Commerce and Defense and the National Aeronautics and Space Administration. Industry partners are working with FAA to develop a variety of such materials: Dow Corning is working on siloxane polymers; Allied Signal on new fire-resistant triazine resins; CIBA-Geigy on advanced cyanate ester resins; and Akzo Chemical on phosphorous-based, fire-retardant chemistry. University partners are studying the properties and processing of such materials and the mechanisms of fire resistance.

materials science, computational modeling tools, and NDT sensors and methods; high-performance materials for infrastructure renewal and new development; and automation and robotics technologies for construction, repair, and inspection.

Materials R&D Related to National Priorities

Aeronautical Materials Technologies

The FAA supports a number of R&D programs addressing materials for aeronautical applications. The FAA conducts research on fire-safe materials for aircraft cabin interiors; advanced materials for low-maintenance runway pavements; and assists in crash, explosion hardening, and fire testing of new aircraft structural materials and components. The FAA also supports development of new safety and security inspection procedures, maintenance methods and materials, and associated safety certification. In addition, DOT supports numerous industrial R&D projects dealing with materials for aeronautical applications, such as advanced sensors for ice detection on aircraft wings.

Automotive Materials Technologies

NHTSA participates in the interagency Partnership for a New Generation of Vehicles (PNGV), primarily to ensure that lightweight advanced materials to be used in future cars meet or exceed crash safety standards, and that components and the overall PNGV system performs safely in fires, explosions, and any other foreseeable accident. In addition, many industrial projects supported by DOT involve advanced materials and manufacturing technologies for automotive structures.

Electronic Materials Technologies

The FAA conducts a small amount of R&D involving electronic materials used in radar, luggage surveillance, and communications systems. All modes conduct some research on the safety and operability of new electronic materials, such as "smart cards" used for tagging, tracking, and locating transportation vehicles, hazardous materials and containers, and for "intelligent" fare and electronic toll collection.

Infrastructure Materials Technologies

DOT supports a broad range of R&D activities focusing on traditional or advanced materials for infrastructure applications, such as roads, bridges, port structures, and runways. Materials of interest include high-performance and prestressed concrete, asphalt, high-strength steel, weather- and corrosion-proof coatings, and safety appliance materials. In addition, FHWA works with the National Institute of Standards and Technology (of the Department of Commerce) to develop performance standards for advanced infrastructure materials, quality assurance, and NDT sensors, methods, and failure models.

Interaction with the Private Sector

Due to the nature of its activities, DOT must coordinate its programs with state and local governments, public transportation authorities, and the various transportation industries (manufacturers, suppliers, operators, and services providers). In addition to these routine cooperative efforts, technology transfer is accomplished through the full participation of DOT research centers in the Federal Laboratory Consortium, in the awarding of R&D contracts to the private sector, and in Cooperative Research and Development Agreements with industrial partners addressing a wide range of topics. The DOT also manages and participates in numerous special programs that support academic and industrial R&D, such as the Small Business Innovation Research (SBIR) program.

RSPA coordinates several academic programs that involve some materials R&D: the University Transportation Centers Program (UTCP), University Research Institutes (URI), and Centers of Excellence (COE). The UTCP was established in 1987 to focus on long-term applied research, primarily for surface transportation applications. The network encompasses 13 regional centers, 10 of which are consortia. The UTCP is supported by FHWA and the Federal Transit Administration (FTA), with matching grants from state and industry participants in each regional consortium. The five URI programs also are funded by FHWA and FTA and managed by RSPA. Only one URI, the Infrastructure Technology Institute at Northwestern University, emphasizes materials R&D and associated design and construction technologies.

Also in the academic arena, the FHWA, in cooperation with the State University of New York-Buffalo and a large support consortium, conducts R&D aimed at improving and implementing seismic design guidelines for bridges and highways. The USCG and MARAD support four universities designated as National Maritime Enhancement Institutes. The FAA, together with the National Aeronautics and Space Administration, supports a Joint University Program and several Air Transportation COEs. All the FAA centers address materials R&D, including development of advanced airport pavement designs, materials, and modeling tools; and development of data and models for analysis of aging aircraft, extension of their useful life, and new structural designs.

DOT also participates in several interagency Federal R&D partnerships. As a partner in the Advanced Technology Program, DOT supported and helped select industry projects addressing vehicle technologies, such as new sensors for ice detection on aircraft wings, and advanced materials and manufacturing for automobiles. In the Technology Reinvestment Project (TRP), DOT has managed and participated in a number of major materials-related activities, including projects on advanced composites for bridge infrastructure renewal and seismic strengthening; adaptation of land-mine detection technology for assessment of soil compaction for civil construction; advanced shipyard repair and maintenance technologies and shipbuilding materials; and advanced electric and hybrid vehicles utilizing new materials for power sources and power trains.

As part of the TRP, DOT helped select and manage transportation-related SBIR awards, some of which pertain to advanced materials. Recent topics include an automated pavement distress survey system; thin-metal-film battery technology featuring low cost, high power, and quick recharge; high-temperature engine and electronics technologies for energy-efficient, low-emission cars; fabrication of composite turbine powershafts; and processing of ceramic core composite skin structures for next-generation aircraft.

DOT's internal SBIR program is managed by RSPA's Volpe National Transportation Systems Center. Recent materials-related topics include advanced fire suppressants and fire-resistant cabin materials; advanced NDE methods for polymer composites; integrity of aging aircraft; security screening for luggage materials; development of NDE methods for assessment of weld integrity in tank cars on trains; remote sensing technology for the detection of structural fatigue cracks; assessment of the use of recycled materials in concrete; and NDE methods for monitoring composite-bonded aircraft structure, detecting widespread fatigue damage in aging aircraft, and predicting failure of turbine engines.

Materials R&D Base Programs

Federal Aviation Administration

The FAA is responsible for encouraging and fostering the development of safe and efficient national airports, promoting advances in commercial aircraft, and operating a safe and efficient aviation system. The FAA works with a wide range of advanced technologies, including navigational aid and traffic management systems, radar network systems, advanced communications networks, display units, aircraft, aircraft components and structures, aircraft landing and traffic control systems, and computers and software. Many of these technologies are included in the agency's comprehensive National Airspace System Plan for modernizing and improving air traffic control and airway facilities services through the year 2000.

Many FAA projects involve materials R&D in support of aircraft safety, airport technology (including pavements and security technology), and operational safety and efficiency. For instance, the Airport Technology R&D Program provides new and improved standards, criteria, and guidelines for planning, design, construction, operation, and maintenance of U.S. airports. This is a timely focus area, because airport pavements nationwide are approaching the end of their design life, and new materials (such as those used in the new Denver International Airport) may increase pavement life by 10 percent and save $200 million a year in maintenance costs. Moreover, new pavement materials and designs are required to accommodate aircraft that will be used to handle the anticipated growth in landside airport capacity.

Specific materials-related R&D thrusts include airport pavement materials, designs, modeling, testing, and construction technology; airport security technology, with an emphasis on NDI and explosives detection technologies; advanced materials for engines, fuselages, and hardened containers that meet airworthiness and crashworthiness standards; advanced fire-safe materials for aircraft cabin interiors and

New Concrete Foam May Help Huge Aircraft Stop

A new lightweight concrete material, in the form of phenolic foam, shows promise for enabling large aircraft to stop safely over very short distances, without overrunning runways under hazardous takeoff or landing conditions. The new material, now being developed and tested by FAA researchers and ESCO / Datron of Aston, Pennsylvania, may help resolve an emerging airport safety problem. The nation's 7,800 airports with paved runways are aging, and the current $2 billion maintenance program cannot accommodate the projected growth in air traffic. New pavement designs, materials, and technologies are needed to support the introduction of extra-large commercial aircraft, such as the recently introduced Boeing 777. Current runways are not long enough for these planes, and land-use constraints preclude many older airports from extending runways to provide the FAA-mandated 1,000-foot safety zone between the end of a runway and a highway, body of water, or other potential hazard. Many potential runway materials have been tested by the FAA since 1987. The new concrete arrestor material promises short stopping distances with maximum safety, while allowing fire and emergency rescue equipment access to the aircraft.

structural components, as well as nontoxic fire-fighting materials; and aging aircraft and catastrophic failure prevention research, emphasizing improved NDI, failure modeling, and patching materials.

Federal Highway Administration

The FHWA administers, in cooperation with the states, the Federal Aid Highway Construction Program, which includes new primary, secondary, urban, and interstate projects, and preservation of existing highways through resurfacing, restoration, rehabilitation, and reconstruction. FHWA research focuses on materials and equipment for rebuilding, strengthening, and preserving the aging U.S. highway system.

Materials Database Improves Management of Runway Pavements

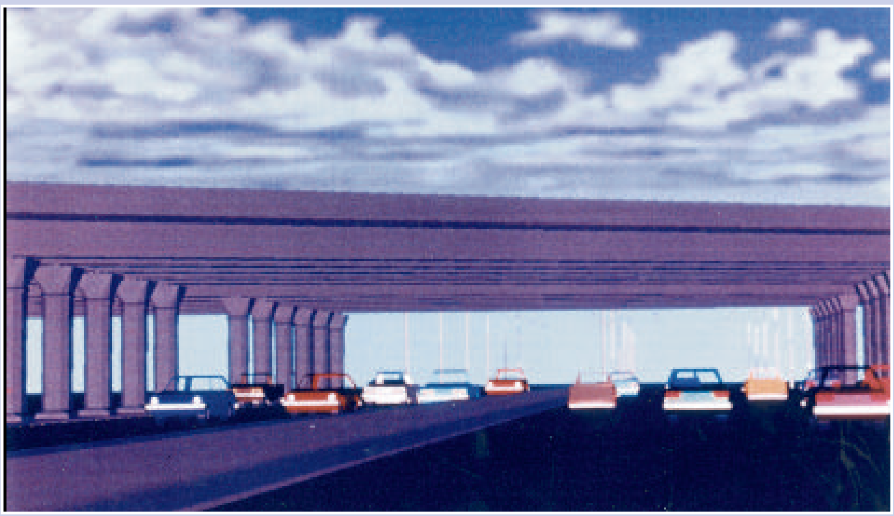
The condition of airport runways in Virginia has improved, while maintenance costs have dropped, thanks to a computer-based pavement management system used to monitor the condition of runways in the state's 70 public airports. The system, developed by FAA researchers and private sector partners, has been used by the Virginia Department of Aviation for the past four years. The system employs a pavement condition database based on statistical sampling of representative pavement material types (asphalt, taxiways, aprons, and concrete pavements) and information about how they are expected to perform, degrade, and fail over time as a function of traffic wear and climatic conditions. The data are collected over time, and a decision analysis model, combined with a failure model that can predict performance, is used to rank rehabilitation alternatives and set priorities and schedules for airport pavement repair. Pavement condition already has improved, while life-cycle and maintenance costs have been reduced.

Pavements and structures R&D emphasizes improvements in and new uses for traditional materials, including recycled waste and hazardous materials for use in highway applications and improved materials for use in highway construction. Materials under study include high-performance concretes, high-strength steels, aluminum, fiber-reinforced-plastic (FRP) composites, high-strength timber, and coatings and adhesives for use as components of highway structures. New NDT methods for performance monitoring, accelerated pavement testing methods and systems, and robotics inspection and pothole-filling systems are under development.

Other FHWA funds are redesignated by the states for the National Cooperative Highway Research Program (NCHRP). About half of the NCHRP is devoted to improving materials and design aspects of the highway infrastructure, while the other half focuses on safety, environmental, and operations research. In addition, a substantial share of FHWA block grants to the states is spent on almost 1,000 R&D projects annually, usually conducted by contractors at state universities.

Other FHWA R&D activities aimed at upgrading in materials and technologies used in renewal and construction of bridges, highway pavements, and safety structures include:

- the Long Term Pavement Performance Program, established to compile a 20-year, comprehensive database of the in-service performance of 2,500 representative pavement sections nationwide;
- the Strategic Highway Research Program, which recently completed a five-year cooperative effort focusing on advanced technologies for asphalt pavements, Portland cement and structural concrete, de-icing materials and safety, and pavement performance; and
- the Advanced Research and Technology Program (created by ISTEA), which focuses on demonstration of new materials and robotics for infrastructure applications and advanced NDI/NDE technologies.



High-Performance Concrete Bridge to Save Time and Money

A bridge made of high-performance concrete (HPC) decks and pillars, cast and processed using advanced methods, is being demonstrated through a joint effort of FHWA and the State of Texas. The bridge features advanced NDI/NDT devices to monitor strain and performance during and after the construction process. The HPC has greater strength, durability, and resistance to weathering than does traditional concrete, and therefore requires fewer pillars to support longer spans and a lighter superstructure. While HPC is more expensive than conventional materials, the added cost is more than offset by savings in construction and life-cycle costs and building time.

National Highway Traffic Safety Administration

NHTSA's R&D activities include modeling and testing vehicle crashworthiness and studies of human factors related to passenger safety and injury prevention and mitigation. Materials science is a key component of the R&D program, not only in modeling of vehicle material behavior and injury potential in crashes but also in test and evaluation of improved bumpers, protective padding and fire-safe materials for car interiors, and reflectors for cars, roadway signs, and safety appliances. NHTSA is also the focal point for DOT's participation in the PNGV.

Materials Modeling and Testing to Enhance Train Safety

The safety of future high-speed trains, which will be made of strong-but-lightweight advanced composites, will be assured through sophisticated modeling and testing carried out by DOT's Volpe National Transportation Systems Center. To support the FRA's recent efforts to develop high-speed rail safety standards, Volpe Center researchers adapted school-bus interior padding and restraint specifications, using NHTSA-validated models to study occupant dynamics and predict fatalities for passengers involved in high-speed train collisions, and to evaluate various interior cabin configurations and padding and passenger restraint requirements. The results of the analysis will enable the emerging high-speed rail industry to meet performance safety requirements for next-generation trains, which will be made of materials that are even lighter and stronger than today's composites. The Volpe Center provides engineering support for crashworthiness research in all transportation modes, using sophisticated three-dimensional finite element and biomechanical models.

Coast Guard and Maritime Administration

The USCG enforces Federal laws, including fisheries laws, on the high seas and in U.S. navigable waters and carries out a broad range of other coastal safety, security, and environmental protection activities, including search and rescue missions and enforcement of fire safety regulations. All operations are highly dependent on knowledge of the properties and performance of materials. The limitations of current materials are evident in the operation of ships and planes, their power and propulsion units, and armaments. Less obvious are the strains on materials imposed in search and rescue or ice operations, the insidious corrosion that shortens the operational life of many materials and leads to hull fractures and oil spills, and the materials-limited capabilities of navigational aids and surveillance equipment.

The USCG, in cooperation with MARAD and other Federal and industry partners, participates in the NAS Ship Structures Committee's research program, designed to advance the design, construction, longevity, and safety of government and commercial fleets through the use of new materials and technologies and the sharing of data and models. Lightweight, strong, corrosion-proof composites and special coatings and corrosion-protection methods have been developed and demonstrated.

The USCG also operates a large fleet of aircraft and boats for drug interdiction and safety assurance, and it conducts extensive research on fire safety for ships and aircraft. Research topics include the fire behavior, safety, and toxicity of composite airframes.

MARAD has been engaged in revitalization of U.S. commercial fleets and shipyards, in close cooperation with the Department of Defense and the maritime industry. New technologies, including new materials and coatings and manufacturing and welding methods, will be infused into the industry as a result of this effort as well as TRP projects under way at U.S. shipyards.

Federal Railroad Administration and Federal Transit Administration

The FRA carries out a variety of activities aimed at maintaining and improving rail transportation, including R&D in support of improved railroad safety and national rail transportation policy. The R&D program covers safety technology; derailment prevention through improved inspection and maintenance of track, ties, locomotives, and rail car wheels and couplers; and expansion of the technology base and safety assurance for the next generation of intercity ground transportation. Topics include improved methods for automated inspection and testing of track and tie integrity and bridge and tunnel structures, and for damage detection in wheels, tank cars, and hazardous materials containers. Failure prediction models are being developed to improve maintenance scheduling.

Pipeline Wrap Material Guards Against High-Pressure Fracture

A new composite-reinforced wrapping material, now being tested in the field, appears to prevent running fractures on high-pressure transmission pipelines. Developed by Clock Spring with DOT support, the composite sleeve material is a polyester resin reinforced with fiberglass, installed in coil form and held in place with a methacrylate adhesive. The adhesive bonds to the pipe surface and to the layers of coil composite reinforcement. The RSPA accepted this new repair method (under a waiver from current regulations) to enable in-service testing by one transmission company in 1993 and by 28 others in 1995. The new material is one result of a broad R&D effort aimed at preventing accidents along the more than 1.5 million miles of petroleum and natural gas pipelines in the United States. RSPA's materials-related R&D addresses corrosion protection of pipelines and tanks; high-strength structural materials, including steels, composites, and plastics; development of effective NDI methods; acquisition of stress and corrosion data; and enhancement of modeling tools that predict material failure.

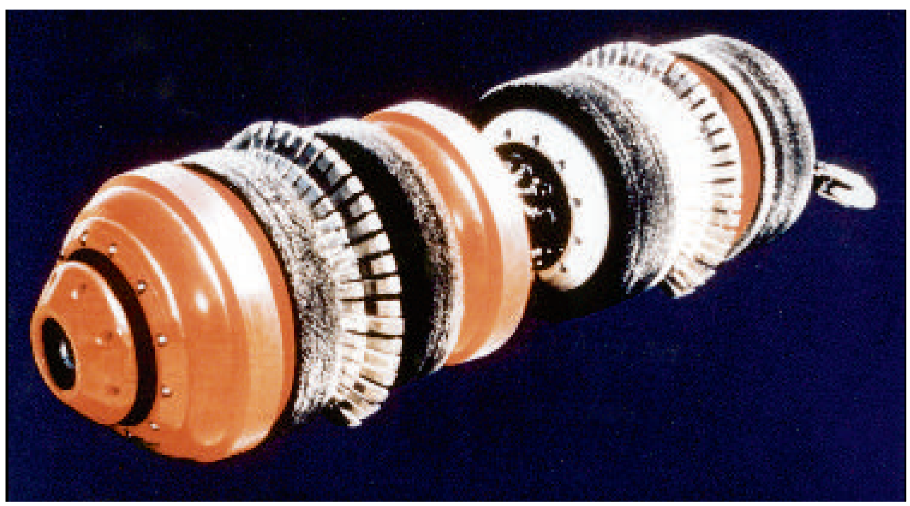


Photo of a Tuboscope™ "smart pig". Such instrumented NDT sensors flow with the pipeline fluids and identify wall thinning due to corrosion and mechanical damage (dents, gouges).

There is a significant materials R&D component in the high-speed rail development effort, which includes assessment of the commercial feasibility of magnetic levitation service in the United States. Materials-related topics include potential applications of superconductors for power generation, storage, and propulsion; nonmagnetic polymer composite materials for vehicles, locomotives, and guideway construction; applications of high-strength steel to continuously welded rail; pre-tensioned concrete and FRP components for guideways; applications of photonic materials for guideway integrity and intrusion detection; layered track beds for high-speed operations; materials for lightweight trains and engines that meet crashworthiness standards; and advanced power and propulsion technology.

Generic materials-related R&D for freight and passenger rail addresses track and equipment corrosion-protection methods; NDE for rail track, containers, couplers, and wheels inspection; development of fire safety standards and interior padding for railcar interiors; and seismic design, monitoring, and automated inspection of railroad bridges. The FTA pursues similar goals with respect to guideways and vehicles for passenger use and is concerned with safety, lightweight vehicles, and overall energy efficiency.

Research and Special Programs Administration

In addition to managing the UTCP, SBIR, and other DOT-wide special programs, RSPA is responsible for assuring the safety of pipeline and hazardous material transportation and carrying out activities related to emergency preparedness, safety training, and multimodal R&D. Materials R&D is an important component of these activities.

The Office of Hazardous Materials Transportation coordinates and controls the DOT multimodal hazardous materials regulatory program. Materials R&D activities address lightweight, high-strength, corrosion-proof materials for containers holding hazardous materials, as well as certification standards and NDI techniques to assure container integrity.

The Office of Pipeline Safety, which regulates transportation of gas and hazardous liquids by pipeline, conducts materials R&D aimed at finding improved methods of preventing and combating corrosion (e.g., plastic piping, coatings, effective cathodic protection), as well as NDI methods for detecting pipe degradation, such as a self-propelled inspection robot and failure prediction tools.

RSPA also operates the Volpe National Transportation Systems Center, a multimodal R&D center integrating technical, economic, logistics, and human factors expertise. Materials R&D is conducted at Volpe Center for DOT and other Federal sponsors, including the FAA's aging aircraft research program; NHTSA's vehicle crashworthiness program and biomechanics modeling; and FRA's modeling of track/vehicle interactions, research on crashworthiness of locomotives and interior padding, and development of restraints and seating configurations for high-speed rail cars.

Major Laboratories and Centers of Excellence

FAA Technical Center
Atlantic City, NJ

FRA/AAR Transportation Test Center and
Hazardous Material Training Center
Pueblo, CO

FTA Bus Testing Facility
Pennsylvania Transportation Institute
State College, PA

John A. Volpe National Transportation
Systems Center
Cambridge, MA
Mike Moroney
Aeronautical Center
Oklahoma City, OK

NHTSA Vehicle Research and Test Center
Liberty, OH

Turner-Fairbank Highway Research Center
McLean, VA

U.S. Coast Guard Research and Development
Center
Groton, CT

University Transportation Centers Program consortia are located at the following institutions:

- Region 1 - Massachusetts Institute of Technology
- Region 2 - City University of New York
- Region 3 - The Pennsylvania State University
- Region 4 - University of North Carolina
- Region 5 - The University of Michigan
- Region 6 - The Texas A&M University System
- Region 7 - Iowa State University
- Region 8 - North Dakota State University
- Region 9 - University of California-Berkeley
- Region 10 - University of Washington

Other UTCP centers:

National Center for Transportation and Industrial Productivity, New Jersey Institute of Technology

National Center for Transportation Management, Research and Development, Morgan State University, Md.

Mack-Blackwell National Rural Transportation Study Center, University of Arkansas.

National Maritime Enhancement Institutes:

Massachusetts Institute of Technology

University of California, Berkeley

Louisiana State University, Baton Rouge

University of Memphis, Tennessee

FAA/NASA Air Transportation Centers of Excellence:

Pavement Research Center

University of Illinois, Champaign-Urbana

Computational Modeling of Aircraft:

Rutgers University

Georgia Institute of Technology

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Special report: *Advanced Materials Research and Technology Initiatives, FY 1994-FY 1996*, DOT Research and Technology Coordinating Committee (RTCC), Materials R&D Subcommittee, March 1995.
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Department of Health and Human Services

HHS Primary Organizational Units Sponsoring R&D Programs in Materials Science and Technology:

National Institutes of Health (NIH)

National Institute of Arthritis and Musculoskeletal and Skin Diseases (NIAMS)
National Institute of Dental Research (NIDR)
National Eye Institute (NEI)
National Heart, Lung, and Blood Institute (NHLBI)
National Center for Research Resources (NCRR)
National Institute for Neurological Disorders and Stroke (NINDS)
National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK)
National Institute of Allergy and Infectious Diseases (NIAID)
National Institute on Deafness and Other Communication Disorders (NIDCD)
National Institute of General Medical Sciences (NIGMS)
National Institute of Child Health and Human Development (NICHD)

Food and Drug Administration (FDA)

Division of Mechanics and Material Sciences

Overview of Materials R&D Activities

Department of Health and Human Services (HHS) materials R&D activities are conducted under the auspices of the National Institutes of Health (NIH) and the Food and Drug Administration (FDA). These agencies oversee research on and development and assessment of biomaterials used in health care. The work of the two agencies is intertwined. Numerous institutes and centers of NIH support biomaterials R&D, while the FDA assesses the long-term effectiveness and safety of existing and new biomaterials and devices.

The United States faces major challenges in the health care field. Thanks to medical advances, both length and quality of life have increased dramatically for most citizens. However, health care costs as a percentage of the gross national product have grown steadily over the last two decades. To reverse this trend, advances will be required that not only offer treatments for previously untreatable diseases but also help increase the effectiveness and/or reduce the costs of treatments for chronic diseases such as diabetes and arthritis. Advanced biomaterials will help meet these needs.

The modern era of medical device implants began in the 1950s with the heart pacemaker, the heart valve, and the artificial hip replacement. Over the next two decades, demands and requirements for medical implants increased, to aid in treatment of many clinical conditions. More than 11 million people in the United States have biomaterial implants, according to a National Center for Health Statistics survey completed in 1988. Three million of these recipients have two implants. The implants covered by the survey were artificial heart valves, arteries and veins, dental materials, artificial joints and fixation devices, intraocular lens implants, drug delivery systems, pacemakers, ear vent tubes, and silicone implants. The survey excluded routine dental restorative procedures and devices, which, of course, are applicable to virtually the entire U.S. population.

The enabling materials used for most medical implants evolved from other research fields, such as aerospace, defense, and energy. While these materials have been successful in first- and second-generation implants, they have not provided the biocompatibility and long-term effectiveness necessary to offer patients lifetime functional replacement of diseased tissue and organs. Achievement of this goal will depend on multidisciplinary research involving materials science, biomedical engineering, and basic and clinical medical sciences.

Only in the last decade has a scientifically mature community of investigators, supported by NIH, the National Institute of Standards and Technology (of the Department of Commerce), and the National Science Foundation, accumulated the body of knowledge needed to build the foundation for advanced biomaterials. These materials can be designed to meet specific clinical needs, such as controlled drug delivery to aid in smoking cessation.

NIH directs programs designed to improve the health of the U.S. population through

- conduct and support of research on the causes, diagnoses, prevention, and cure of diseases; the processes of human growth and development; the biological effects of environmental contaminants; and the related sciences;
- support of the training of research personnel, construction of research facilities, and the development of other research resources; and
- programs for the collection, dissemination, and exchange of information in medicine and health.

To accomplish its mission, NIH supports both intramural and extramural research on biomaterials. The former is conducted within a few of the intramural laboratories that have other primary research objectives, such as molecular hematology or biomedical engineering. Extramural research, conducted primarily at universities, is supported by 24 organizational units of NIH and comprises the bulk of HHS biomaterials R&D. A wide variety of topics is investigated.

The FDA is the principal consumer protection agency for the Federal government. The enabling laws provide FDA authority to ensure that food is safe and wholesome; drugs, biological products (e.g., vaccines and blood for transfusion), and medical devices are safe and effective; cosmetics are unadulterated; the use of radiologic products does not result in unnecessary exposure to radiation; and all of these products are honestly and informatively labeled.

The FDA conducts a wide range of scientific activities, many focusing on materials or devices made of materials. Through its own laboratories and a few extramural research contracts, the FDA develops scientific databases that are useful in setting standards and preparing regulations. Laboratories at FDA headquarters and in the field analyze countless samples of products, and FDA scientists evaluate research reports submitted by product sponsors. The agency also enlists the aid and expertise of outstanding scientists from all over the country. By serving on advisory committees and panels, these experts offer invaluable service in helping the FDA reach decisions, particularly those concerning controversial or new and unusual medical or biologic products.

The FDA Center for Devices and Radiologic Health is responsible for ensuring the safety and effectiveness of medical devices. The center pursues this objective through numerous activities, including pre-market review of life-sustaining devices through rigorous assessment of clinical safety and efficacy data; establishment of requirements for good manufacturing practices and registration of manufacturers; inspection of firms to insure compliance with the established regulations and practices; development of special controls, such as performance standards and education programs for both users and manufacturers; and several types of post-market monitoring programs.

Through its intramural program and extramural research contracts and experts, the center has developed the capability to assess risks by blending techniques from a variety of disciplines, from biomaterials sciences to biotechnology, from hydrodynamics to epidemiology and statistics. For medical devices, risk assessment addresses numerous factors that may result in device failure, such as product design principles, manufacturing quality assurance, reliability assessment, and product failures related to biological responses, material degradation, and user actions.

Materials R&D Related to National Priorities

HHS does not conduct any materials R&D activities related directly to the five national priority areas addressed in this report.

Interaction with the Private Sector

HHS is unusual among Federal agencies in that most of its R&D funding (about 90 percent) goes to outside researchers, including those at universities, nonprofit research centers, and industry. Project topics change constantly, depending on medical needs and interests. Most NIH extramural projects are selected from unsolicited, investigator-initiated proposals for hypothesis-driven basic or applied biomaterials research. These proposals undergo primary review by panels of peers, which judge scientific merit. Secondary review is conducted by advisory councils and boards, which make funding recommendations based on program balance and national priorities. Final funding decisions are made by the directors of NIH and its institutes and centers.

Outside advisers also play a formal role in stimulating support for particular topics. The NIH staff, working with extramural advisory committees, is responsible for keeping abreast of scientific needs and opportunities that require stimulation through NIH-initiated programs. These research programs are initiated through requests for applications, requests for proposals, and program announcements. Seventy percent of biomaterials research is supported through unsolicited, investigator-initiated grant applications, and 30 percent through special grant and contract programs. The FDA also supports a small amount of extramural R&D.

The results of NIH-supported technology development activities are disseminated in a number of ways. The results of grant-supported activities are discussed widely at public meetings and published in technical and medical journals. Fundamental studies usually are published first in journals devoted to biomaterials research. When biomaterials are used as enabling technologies, the research is published in clinical journals. An example would be a study describing the clinical outcome of a new synthetic vascular graft.

The NIH Office of Technology Transfer handles all NIH patent policy issues and implements Cooperative Research and Development Agreements (CRADAs), patent licenses, and other technology-transfer activities, such as education and special conferences to stimulate cooperative R&D and medical transfer agreements. The OTT technology licensing branch conducts negotiations for licensing and other matters with the private sector and academia and develops licensing strategies for the NIH Division of Intramural Research and Inventions, by fostering interaction with potential licensees. The technology transfer coordination branch correlates technology transfer policies and programs among the Public Health Service agencies and other Federal laboratories.

An HHS grant or contract sometimes has a consortial or subcontract arrangement with a private concern that will attempt to commercialize an implant if the results of laboratory and clinical studies are encouraging. Many basic findings have been exploited in this way through the government-wide Small Business Innovation Research (SBIR) program. Generally, a technology activity funded under SBIR must incorporate leading-edge biomaterials if it is to culminate in successful commercialization. The NIH also participates in the Small Business Technology Transfer (SBTT) pilot program, which supports collaborative research involving small businesses and academic researchers.

Examples of SBIR and SBTT projects include the following:

- The National Eye Institute makes wide use of the SBIR and STTR programs to stimulate the commercialization of research results, typically through animal testing of prototype materials and devices prepared using new manufacturing techniques. Such projects involve development of processes such as ion beam scattering to prepare diamond knives for ocular microsurgery, fabrication of ceramic cutting shears for use in ocular surgery, fabrication of very thin polysulfone intraocular lenses, and a simplified method for producing a spectacle lens with adjustable power.
- The National Institute of Neurological Disorders and Stroke supports a number of SBIR biomaterials projects, including development of multilayer thin-film insulating coatings of silicon carbide and silicon dioxide for neural prostheses, new materials for peripheral nerve electrodes, microelectrodes that respond selectively to certain neurotransmitter, and insulating materials for microelectrodes that can be removed selectively by laser ablation.
- The National Institute on Deafness and Other Communication Disorders uses the SBIR and STTR programs to foster development of components with commercial potential for the auditory prosthesis industry. One SBIR contractor is developing a method of using lasers to remove insulation from microelectrodes and exploring the use of biomaterials such as titanium and bioglass in a connector system designed to integrate into bone to provide a safe, stable platform for auditory prostheses. An STTR grantee is improving the function of high-density cochlear electrode arrays by using novel design and fabrication techniques, while also improving reproducibility and reducing costs.

The FDA works with industry to remedy biomaterials shortages and other problems. Manufacturers are concerned about their inability to purchase certain raw materials, particularly implant-grade silicone, used in the production of medical devices. Some vendors have redirected their products to other parts of the commercial sector or to shut down their operations entirely, due primarily to tort liability and poor profit-to-risk ratios. Under the law, the FDA has limited capability to solve the problems facing medical device makers. Nevertheless, some steps have been taken. Guidelines have been developed to help firms decide whether a change in materials warrants premarket review by the FDA and, if so, which tests must be done. (Chemically equivalent replacement materials do not require approval.) With respect to silicone, the FDA has committed to expediting the review of implant-grade silicone alternatives and will allow uninterrupted market availability of a device during review of the substitute material.

Materials R&D Base Programs

National Institute of Arthritis and Musculoskeletal and Skin Diseases (NIAMS)

The objectives of NIAMS biomaterials research relate primarily to musculoskeletal issues. This research effort focuses on devices that now or in the future may be used by orthopedic surgeons and other medical specialists in the treatment and rehabilitation of a variety of medical conditions.

One area of special emphasis has been total joint replacements (TJRs). The institute has offered continuous grant support for research focusing on the design, biocompatibility, and attachment of TJRs, especially for the hips and knees. Because of arthritic degeneration of hip and knee cartilage and osteoporotic fractures of the hip, there are well over 200,000 TJRs of the knee and hip each year. In September 1994, NIAMS led an NIH Consensus Development Conference on Total Hip Replacements. Both third-generation cemented devices and cementless (porous ingrowth) devices were evaluated. The resulting consensus statement was published in the Journal of the *American Medical Association* in April 1995.

The technology of TJRs for hips and knees has evolved in the past decade to include a new attachment approach, in which a porous stem allows bone to grow into the surface of the device and presumably form a more permanent attachment than is possible with the traditional, cemented approach. NIAMS has supported a wide variety of research on the nature and optimization of the porous material/bone interface. Long-term benefits of the porous ingrowth attachment will not be known until the current generation of implants is in place for more than 10 years.

Another major area of research interest is biological repair of large defects, such as injuries and tumors, in bones and joints. Transplantation of bone or bone and cartilage from the patient (an autograft), or from another person (allograft), allows replacement tissue to become biologically alive and permanently functional. A variety of competitive grant mechanisms have been used to support this research, which has addressed graft preservation, host immune response, and microvascular reattachment.

In FY 1994, through special funding provided for non-traditional biomaterials research, NIAMS initiated a Program of Excellence in Orthopaedic Biomaterials. Four applications were funded, including three computerized, interactive research projects focusing on biomaterial effects on osteoclastic bone resorption, enhanced attachment of prosthetic devices to bone, systemic release of wear particles from total hip replacements, and osteoblastic bone formation.

National Institute of Dental Research (NIDR)

The mission of NIDR is to conduct, foster, and support research and research training into the causes, prevention, diagnosis, and treatment of oral diseases and conditions. NIDR biomaterials research includes studies to develop new and improved materials, methods, and technologies for the treatment of dental diseases and restoration of dental function. Technologies of interest include restorative filling materials, bonding agents, tooth surface sealants, adhesive coatings and cements, intra-oral prostheses for the replacement of missing teeth, bone augmentation materials, and materials and techniques for improved endodontic therapy.

Biomaterials research also includes development of improved maxillofacial prosthesis materials for soft tissue repair and rehabilitation, development of noninvasive and nondestructive diagnostic systems and preventive coatings, and controlled clinical studies to evaluate the performance of new and existing diagnostic, preventive, and treatment materials and methods. The emphasis is on research related to biocompatibility of materials, durability, restoration of function, and patient satisfaction.

National Eye Institute (NEI)

The mission of NEI is to conduct, foster, and support research and research training addressing the normal functions of the eye and visual system, the pathology of visual disorders,

Polymer Blend May Improve Drug Delivery to the Eye

A new form and combination of two traditional polymers, developed through HHS-supported research, appears to be a promising medium for safe, sustained drug delivery to the eye. This advance, the latest development in the evolution of biocompatible sustained-release devices, offers the promise of solving a major problem in the treatment of many ocular diseases. Topically or systemically administered drugs usually achieve poor penetration into the eye, and attempts to increase dosing frequently lead to local or systemic toxicity, while direct intraocular injection can cause trauma, inflammation, and infection. The new material combines two inert membranes: polyvinyl alcohol, which is permeable, and ethylene vinyl acetate, which can be used as an impermeable layer to modulate the release of compressed and concentrated drugs. The materials can be applied much like a contact lens or intraocular implant and offer the possibility of correcting vision while also delivering medication. The general approach has been validated using diverse drug agents. Convincing animal studies were completed with ganciclovir inserts for the treatment of cytomegalovirus retinitis, a common condition in patients with suppressed immune systems. This work was confirmed through preliminary human clinical trials conducted by HHS grant recipients in collaboration with NEI researchers.

and the sciences relating to vision, all to promote progress against the major causes of blindness and visual disability. NEI biomaterials R&D includes development of new biocompatible materials to replace or enhance ocular structures or treat ocular disorders. NEI supports investigator-initiated extramural projects as a means of fostering early conceptualization research in ocular biomaterials. Recent advances in this field have included development of biocompatible devices for sustained release of medications.

Other activities include research in polymer chemistry, to produce substances for ocular bandages, replacement vitreous and aqueous fluids, and controlled drug delivery systems; pharmaceutical chemistry, to develop new ocular therapeutic agents; and materials chemistry, to support the development of ocular implants and lenses. Controlled clinical trials are dedicated to evaluating new biomaterials approaches to the treatment of human eye and vision disorders.

National Heart, Lung, and Blood Institute (NHLBI)

The mission of NHLBI is to conduct, foster, and support research and research training in the normal functions of the heart and blood vessels, lungs, and blood; the pathology of these organs in human disease; and the prevention and treatment of cardiovascular, pulmonary, and hematological disorders. NHLBI biomaterials R&D spans the cardiovascular, pulmonary, and hematologic fields.

In the cardiovascular field, studies focus on development of a biocompatible small-diameter vascular graft, which could replace autologous vein or artery grafts in the surgical treatment of coronary artery disease and peripheral vascular disease; a hybrid organ composed of a biomaterial lattice coated with genetically engineered cells capable of carrying out specific functions, such as delivery of insulin or binding of low-density lipoproteins in the treatment of diabetes or hypercholesterolemia; and an advanced biocompatible blood-contacting surface for the lining of artificial hearts and other devices designed to replace or assist the functions of a failing heart.

In the pulmonary area, investigations focus on development of an improved temporary or permanent artificial lung, for the treatment of both acute and chronic respiratory disorders. In the hematologic field, work is continuing on the development of blood substitutes, which could be administered to patients in the place of transfused blood, thereby eliminating the risk of transmission of infectious diseases, such as AIDS and hepatitis.

New, nontraditional research programs initiated in FY 1994 include three studies on the use of genetic engineering to enhance the biocompatibility of blood-contacting materials in cardiovascular implants. Another program, aimed at overcoming the toxicity problem that impedes development of safe and effective blood substitutes, supports seven studies on the toxicity-inducing mechanisms of oxygen carriers.

National Center for Research Resources (NCRR)

NCRR programs are designed to strengthen and enhance the research environment for investigators supported by other units of NIH. The NCRR provides resources to foster studies of the safety and effectiveness of biomaterials used for medical purposes, as in bioresorbable vascular grafts, transdermal drug delivery systems, intraocular lenses, cardiac pacemakers, hip prostheses, implantable pumps, fracture plates, breast augmentations, and dental implants. The NCRR also supports the activities of the National ESCA (electron spectroscopy for chemical analyses) and Surface Analysis Center for Biomedical Problems, a national resource for chemical analysis of material surfaces.

To predict the performance of implants, researchers must understand the dynamic biological changes occurring at the material/tissue interface. Response mechanisms under study include coagulation, inflammation, thrombus formation, and fibrosis. To assist in these studies, NCRR makes available tools such as new spectroscopic techniques, Fourier transform infrared spectroscopy, laser doppler anemometers, scanning electron microscopes/electron microprobes, and ESCA.

The availability of these tools fosters interdisciplinary molecular research investigating biomaterial surfaces, biocompatibility of new polymeric materials, molecular-based biosensors, absorbable polymers, blood vessel regeneration systems, longevity of implanted transducers, and small vessel prostheses.

National Institute of Neurological Disorders and Stroke (NINDS)

NINDS is the lead Federal agency for the support and conduct of research and research training programs on the normal function of the brain, spinal cord and peripheral nerves, and neurological and neuromuscular disorders. The institute supports biomaterials research by outside investigators through investigator-initiated grants, research training grants, SBIR grants, research program projects, and other mechanisms. Additional biomaterials research is conducted through the awarding of contracts for NINDS-initiated projects, and through intramural research conducted by in-house scientists.

The objectives of NINDS biomaterials research are to evaluate the safety of potential biomaterials used in neurological rehabilitation, to conduct research on new biomaterials and new material processing techniques that would be useful in neurological rehabilitation, and to evaluate and modify conventional materials for biological applications. Current materials development activities focus on electrical insulators and conductors for high-charge-density electrodes, insulating biomaterials for thin-film protection of implanted integrated-circuit electrodes, and micromachining of multiple electrode arrays. New biomaterials under study include bioactive materials for surface modification of microelectrodes to enhance their integration into the nervous system.

Two new projects have been initiated to develop biomaterials that can provide a long-term connection between microelectrodes and the tissues of the brain. NINDS researchers are developing long-chain molecules with sites on one end that chemically bond to the surface of a microelectrode, and sites on the other end that bond to specific receptors on brain cells. These molecules will be used to coat a microelectrode, producing a novel surface designed to interact with brain cells.

National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK)

The mission of NIDDK is to conduct and support basic and clinical research on a wide range of normal and disease states, including diabetes and other endocrine and metabolic diseases, digestive diseases and nutrition, and kidney, urologic, and hematologic diseases.

NIDDK supports biomaterials R&D to improve treatments for a number of diseases. For example, special materials are being developed to improve the survival and function of transplanted pancreas islet cells, liver cells, and bone marrow cells for the treatment of diabetes, liver disease, and inherited metabolic diseases, respectively. Such materials will contribute to the eventual development of artificial organs from cultured cells and tissue.

The institute also supports research on biomaterials for devices used outside the body to mimic and replace impaired bodily functions. Chief among these devices are kidney dialysis machines and insulin pumps. Additional biomaterials research is carried out in the field of biosensing, which employs special materials coated with immobilized enzymes to mimic the body's methods of detecting or metabolizing specific molecules in the bloodstream. Other activities include development of biocompatible surface coatings for devices implanted in the human body.

National Institute of Allergy and Infectious Diseases (NIAID)

NIAID conducts and supports research and research training focusing on the causes of allergic, immunologic, and infectious diseases, and to further development of improved prevention, diagnosis, and treatment methods. In its extramural program, NIAID supports biomaterials R&D related to drug delivery systems for new drugs, viral vectors for delivery of disease-fighting genes, and microencapsulation for vaccine delivery systems, a technique that improves the efficacy of vaccines and treatments for numerous infectious diseases, including AIDS.

National Institute on Deafness and Other Communication Disorders (NIDCD)

NIDCD conducts and supports research and research training focusing on normal mechanisms as well as on diseases and disorders of hearing, balance, smell, taste, voice, speech and language. NIDCD supports biomaterials research through an extramural program of grants and contracts for projects designed to develop substitutes for lost and impaired sensory and communication functions.

Examples of grant-supported biomaterials R&D projects include development of implantable middle-ear hearing devices, development of high-density cochlear electrode arrays, evaluation of existing and new cochlear implant electrode-contact materials, and fabrication of intracochlear electrodes for nonhuman models, as well as several projects on normal and pathological results in cochlear implant patients aimed at improving electrode design and processing strategies.

NIDCD also supports several research contracts that include new applications of biomaterials. For example, one contractor is developing biocompatible electrical insulators and conductors for microelectrodes that will be implanted into the cochlear nucleus of deaf individuals as part of an auditory prosthesis. Another contractor is developing stimulating electrodes that protect auditory nerve fibers in individuals who are deaf as a result of disuse atrophy.

National Institute of General Medical Sciences (NIGMS)

The mission of NIGMS is to support research and research training focusing on basic areas of biomedical science. The majority of studies do not target any particular disease or condition. Rather, NIGMS provides support for basic research with broad applicability to a wide variety of diseases or organ systems. In the area of biomaterials, this research focuses on the development of materials that have the potential for general use. These include materials for use in implants, substrates for artificial skin, in-vivo sensors, or the delivery of pharmaceuticals.

National Institute of Child Health and Human Development (NICHD)

The mission of NICHD is to conduct research to assure that every individual is born healthy, is wanted, and has the opportunity to fulfill his or her potential for a healthy and productive life unhampered by disease or disability. The NICHD biomaterials program is supported primarily through the National Center for Medical Rehabilitation Research. The principal research goal is to enhance or restore useful function in persons with physical disabilities. Materials of interest include those that facilitate the regeneration of missing or injured structures and the design of more effective assistance devices. Such advances could improve dramatically the quality of life, health, and productivity of a large proportion of the nation's 49 million persons with disabilities.

NICHD-supported researchers are developing coating materials that can be used on implanted devices, such as indwelling catheters or electrodes, to increase biocompatibility and reduce infection. In other projects, implantable or cutaneous biosensors are being developed for detecting changes in pressure and skin integrity in order to reduce the incidence of pressure sores and muscle injury. Emphasis also is placed on development of modified natural products that can serve as scaffolding for the regeneration of neurons, cartilage and bone, skin, and other tissues. The resorption rates of polymer matrices are being evaluated to identify optimal scaffolds for tissue regeneration. Finally, NICHD is supporting the development of genetically engineered cell lines that secrete functional growth factors and extracellular matrix molecules to enhance the healing of injured tissues.

The prevention and treatment of chronic wounds is an area of special interest to the National Center for Medical Rehabilitation Research. Decubitus ulcers are a major source of secondary disability for persons with mobility impairments, so support is provided for development of bioelastic matrices that can serve as drug delivery vehicles. Further, modified biological scaffolding materials are being characterized that enhance the regenerative capacities of soft tissues.

FDA Division of Mechanics and Material Science

The Division of Mechanics and Material Science is one of five analytical and experimental laboratories in the FDA Center for Devices and Radiological Health, Office of Science and Technology. The division is responsible for establishing and maintaining an integrated biomaterials and mechanical engineering capability. The goal is to predict the reliability of devices, specifically by predicting biological service, the effect of environment and manufacturing history on the structure and physical properties of biomaterials, and the effects of device design and application on device reliability during laboratory or clinical use.

Activities include development of measurement methods and analytical procedures for evaluating product performance and reliability, research to expand fundamental understanding of the mechanical behavior of material properties and the biostability of biomaterials used in medical devices, maintenance of the scientific and engineering expertise needed in the evaluation of medical device performance, identification of emerging technologies that could have an impact on future regulatory programs, and development of materials databases to facilitate evaluation of device reliability performance under service conditions.

Major Laboratories and Centers of Excellence

HHS does not support any major biomaterial laboratories or large centers of excellence.

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Annual Reports

HHS does not prepare annual reports on materials R&D.

National Aeronautics and Space Administration

NASA Primary Organizationl Units Sponsoring R&D Programs in Materials Science and Technology:

Office of Aeronautics

Office of Space Access and Technology

Overview of Materials R&D Activities

The National Aeronautics and Space Administration (NASA) is responsible for planning and conducting space missions focusing on space sciences, transportation research, and space exploration, and for planning and managing civilian R&D activities in aeronautics and space. NASA research programs cover a broad range of technological disciplines and include the development and utilization of unique national facilities. Collaborators include other Federal agencies, state, local, and foreign governments, educational institutions, and private industry.

The NASA Strategic Plan establishes a framework for making management decisions by separating key agency activities into five strategic enterprises. The Aeronautics Enterprise (Office of Aeronautics) and the Space Technology Enterprise (Office of Space Access and Technology) are the two that focus on research and technology development that includes materials for engineering applications.

Research in space and aeronautics is conducted primarily at NASA centers in California, Ohio, Virginia, and Alabama. Each center has unique facilities and staff expertise. All of the centers conduct extensive in-house research utilizing special facilities and equipment, as each conducts cooperative R&D with other government agencies, universities, and industry.

The Ames Research Center, located in Northern California, specializes in research, exploration, and applications geared toward information technology. Major programs include computer science and applications, computational and experimental aerodynamics, flight simulation, flight research, hypersonic aircraft, rotorcraft and powered-lift technology, aeronautical and space human factors, life sciences, space sciences, solar system exploration, airborne science and applications, and infrared astronomy. The center also supports national security programs, the space shuttle, and various civil aviation projects.

In advanced materials and processing, Ames researchers focus on computational chemistry and the development of lightweight materials for thermal protection systems. Computational chemistry and modeling of molecular-scale processes, such as gas-gas and gas-solid reactions, provide capabilities for design of unique materials for specific applications and for prediction of material properties and optimal processing conditions. Advanced lightweight ceramic and carbon-carbon composites, as well as other refractory materials systems, are being developed for thermal protection of high-speed aircraft, hypersonic vehicles, and re-entry vehicles.

The Dryden Flight Research Center, also in California, specializes in flight testing of research aircraft. Specialized ground-test facilities include a high-temperature loads-calibration laboratory, which allows testing of complete aircraft and structural components under the combined effects of mechanical and thermal loads.

The Lewis Research Center, in Ohio, concentrates on advanced aerospace propulsion and space power systems, as well as microgravity materials science and applications. Research and technology expertise falls into four main categories: aeropropulsion, space propulsion, space power, and space science and applications. Materials research concentrates on meeting the needs of NASA and the nation for long-range technology innovation, basic research, and project support.

The center's current emphasis on metallic composite research encompasses intermetallic compounds, refractory metals, and new fibers for use in engine components for the space shuttle; advanced subsonic, supersonic, and hypersonic aircraft; and power systems for the International Space Station. Polymer-matrix composites are under investigation for potential use in aircraft engines operating at temperatures up to 425°C and as lightweight power conductors.

Ceramics research is aimed at developing tough, reliable, high-temperature ceramic composites for turbine engines. Ceramic and metallic coatings are being developed to protect heat engine components in high-temperature corrosive and erosive environments. Lubrication experiments are enhancing understanding of the behavior of interfaces (e.g., solid-to-solid contact) in heat engines, aircraft components, and space mechanisms.

The microgravity environments of the space shuttle and Space Station Freedom offer unique opportunities to improve research on solidification and crystal growth and build on ground-based modeling and process research. These activities are supported by characterization laboratories, which analyze the chemical composition and microstructure of advanced materials.

The Langley Research Center, in Virginia, conducts basic and applied research in aeronautics and space technology. Major research fields include aerodynamics, materials, structures, flight controls, information systems, acoustics, aeroelasticity, atmospheric sciences, and nondestructive evaluation. The various technological disciplines are integrated with methodologies for analysis and enhancement of aerospace systems to develop realistic assessments of new concepts for future aeronautics systems and space missions. Langley is the Aeronautics Enterprise's Center of Excellence for Structures and Materials.

Advanced materials and processing research supports a broad range of applications, including advanced subsonic aircraft, high-speed civil transports, high-performance aircraft, advanced hypersonic and aerospace vehicles, and large space structures and antennas. The emphasis is on development of structural mechanics technology and advanced structural concepts to enable the design of efficient, cost-effective, damage-tolerant composite components that can be subjected to complex loading and demanding environmental conditions.

Polymer composite research is directed toward the synthesis of tough, durable, high-performance matrices and the understanding of relationships among molecular structure, neat resin properties, and composite properties. Research also emphasizes advanced space-durable materials and structural designs for future large space systems that offer significant improvements in performance and economy.

Research also is performed at the Jet Propulsion Laboratory (JPL) in California and at the Marshall Space Flight Center (MSFC) in Alabama. JPL is engaged in activities associated with deep-space automated scientific missions, including engineering subsystem and instrument development and data reduction and analysis required by deep space flight. The laboratory designs and tests flight systems, including complete spacecraft, and provides technical direction to contractors. MSFC is a multi-project management and scientific and engineering R&D establishment, with an emphasis on investigation and application of space technologies to the solution of problems on Earth as well as in space. The center plays a key role in many NASA mission operations. Marshall had a significant role in the development of the space shuttle and continues to manage the orbiters' main engines, the external tanks that carry liquid oxygen and liquid hydrogen for those engines, and the solid rocket boosters, which, together with the engines, lift the shuttle into orbit.

Materials R&D Related to National Priorities

Aeronautical Materials Technologies

Aeronautics research in advanced materials and processing is aimed at improving the performance, durability, economy, and environmental compatibility of civil and military aircraft. Due to evolving materials and structures requirements, NASA increasingly has emphasized advanced metals and polymer-matrix composites for airframe structures, and several types of composites (high-temperature polymeric, metallic and intermetallic, and ceramic-matrix) for subsonic and supersonic turbine engines.

Automotive Materials Technologies

Materials and associated processes and engine technologies originally developed for aeronautical and space applications also could be used in the automotive industry. For example, lightweight titanium alloys could be used in auto structures, and fuel cells in innovative auto power systems.

Electronic Materials Technologies

NASA conducts materials R&D related to flight controls, information systems, and other electronics technologies. For example, 11 projects under way in collaboration with

High-Displacement Ceramic Materials Developed for Actuator Application

A new class of piezoelectric ceramics, termed Reduced And Internally Biased Oxide Wafers (RAINBOWs), has been developed through NASA-supported R&D, enabling reductions in size and power requirements for conventional actuator systems, which are used as indirect controls in a variety of technologies. RAINBOWs exhibit electric polarity (like all piezoelectric materials) and are capable of very high axial mechanical displacements under moderate loads (85 pounds per square inch). In addition, multiple wafers can be stacked together to amplify linear displacements. A new processing method was developed to produce the wafers, which can be fabricated in a wide variety of sizes, ranging from 0.5 to 4 inches in diameter. Potential commercial applications include transducers (loudspeakers, tweeters, etc.); ultrasonic generators (ultrasonic cleaners, sonar, ultrasonic welding, pest control devices); sensors (pressure sensors, accelerometers); high-voltage generators (gas igniters, spark pumps, impact fuses); and optics (adaptive optics, variable-focus lens and mirror assemblies).

industry focus on microelectromechanical systems (miniature machines), an effort that complements a larger Department of Defense program.

Environmental Materials Technologies

NASA conducts research on materials and processes related to development of low-noise, low-emissions engines for future high-speed civil transport aircraft.

Interaction with the Private Sector

NASA provides research grants to numerous universities through a variety of programs and works closely with industry on joint technology development. NASA also develops and coordinates joint programs with other government agencies, including the departments of Defense, Energy, and Transportation. The results of NASA research in advanced materials and processing are disseminated through formal Technical Reports, Technical Notes, and Technical Memoranda, as well as other technical publications and patents, invited lectures, workshops, and symposia.

The U.S. Congress has recognized NASA's unique role in technology transfer and has charged the agency with stimulating the widest possible use of its technology. The storehouse of technology built by NASA over more than 30 years can be put to additional use in developing new products and processes that can benefit the Nation's economy by generating new companies, new jobs, and increased productivity.

The instrument for promoting this allied use is the Technology Utilization Program, which employs several mechanisms to stimulate the transfer of aerospace technology to the private sector. Each NASA research center has a Technology Utilization Office (TUO), which is responsible for staying abreast of R&D activities that have significant potential for generating transferable technology. The TUOs foster liaisons among center researchers and industry representatives.

Support for the TUOs -- and for all other elements of the technology utilization network -- is provided by the NASA Scientific and Technical Information Facility, which maintains all NASA publications. The major publications of the Technology Utilization Program are:

NASA Tech Briefs. These contain information on new products and processes, advances in basic and applied research, improvements in shop and laboratory techniques, new sources of technical data and computer programs, and other innovations originating at NASA field centers or at the facilities of NASA contractors. Published monthly.

Spinoff. This is an illustrated summary of major NASA aerospace programs, their goals and directions, their contributions to U.S. scientific and technological growth, and their potential for practical benefit. Published annually.

NASA Patent Abstracts Bibliography. This is a compendium of NASA-patented inventions available for licensing. Published semi-annually.

The Technology Utilization Program also includes a network of 10 university-affiliated Industrial Applications Centers, which offer access to a national technology data bank, and 11 Centers for the Commercial Development of Space. Two of the latter centers offer expertise in aerospace materials and processing: the Consortium for Materials Development in Space at the University of Alabama, and the Space Vacuum Epitaxy Center at the University of Houston.

NASA collaborates with industry in several unique programs focusing on aeronautical materials R&D. In the Advanced Subsonics Technology (AST) Composites program, which targets airframe applications, research on composite materials and processes is aimed at improving structural performance, particularly through increased damage tolerance, while reducing processing and fabrication costs. Automated manufacturing approaches, such as filament winding, pultrusion, automated fiber-tow-tape placement, and resin transfer molding, are combined with fast, efficient alternative energy sources, including laser, ultrasonic, and induction heating, to reduce costs by 50 percent or more compared to conventional hand-layup and autoclave cure methods. Automated textile processes, such as two-dimensional and three-dimensional weaving, braiding, stitching, and knitting, are used to fabricate near-net-shape structural elements with significantly improved damage tolerance. This program also is developing analytical process models and in-situ sensors to optimize resin infiltration and cure. The successful application of advanced composites hinges on generation of a design database encompassing an understanding of failure mechanisms and the development of life prediction methods verified by large-scale structural testing.

The Advanced High-Temperature Engine Materials Technology program focuses on developing revolutionary composite materials and structures technologies for 21st-century turbine engines. Materials of interest include high-temperature polymeric-matrix composites, metal/intermetallic-matrix composites, and ceramic-matrix composites. Composites have been fabricated that maintain strength and toughness after thermal cycling from room temperature to 1100°C for more than 500 cycles

Composite Wing Demonstrated for Future Commercial Aircraft

The strength of a non-metallic aircraft wing was demonstrated in July 1995, a major milestone for NASA's Advanced Subsonics Technology Composites Program. The demonstration paves the way for development of a composite wing for use on future commercial transport aircraft that will save significant amounts of weight and therefore fuel costs. The composite wing "stub box" was developed jointly by McDonnell Douglas Aerospace and NASA's Langley Research Center. The stub box represents a full-size transport wing structure from the fuselage outboard for a span of 12 feet. A series of design-limit load conditions were imposed to the assembly, in which the upper cover had been impacted on purpose and then repaired. Then the box was loaded to failure, which occurred at 93 percent of the ultimate load of the design. Based on knowledge gained from earlier tests of elements of the wing box, it is believed that minor design changes will yield the required wing strength without weight or cost penalties.

without failure. Advanced analysis, design, and life prediction methods are being developed for these materials to enhance understanding of composite architecture, processing, fiber-matrix interaction, and failure mechanisms at elevated temperatures.

The High Speed Research program is developing the technologies to enable construction of the next-generation supersonic airliner. Two components of that program are significant materials efforts. The Enabling Propulsion Materials subprogram is developing propulsion materials, while the Airframe Materials subprogram is focusing on advanced structural materials, structures, and accelerated test methods.

Materials R&D Base Programs

Aeronautics Research and Technology

Research in advanced metal alloys, polymers, ceramics, and composites can give the United States a technological advantage in the international market for a new generation of supersonic airliners. Advanced aluminum alloys and composites could be used in airframes structures to reduce their weight, and advanced ceramic and intermetallic composites can enable the development of affordable engines operating at acceptable noise and emissions levels.

The Aeronautics Research and Technology Base program seeks to develop structures and materials technologies needed to increase the efficiency and competitiveness and reduce the cost of next-generation aircraft. Such innovations include the introduction of advanced composite and metallic materials into primary aircraft structure and the introduction of high-temperature materials into engines.

To enable the economical use of advanced materials in primary airframe and engine structures, design cycle time and manufacturing costs must be reduced, and structures must be designed to be durable and damage tolerant. Therefore, NASA is developing both the advanced materials and the associated processing and fabrication technology. Computational models and thermal analysis methods are being developed for integrated, optimal airframe design. Analytical models for predicting the failure of structures are under development, and full-scale components will be tested to verify the models. Mechanics models that describe the deformation, strength, and life of advanced materials also will be developed and included in structural models.

To ensure aircraft safety, advanced methods for prediction and control of aeroelastic and structural dynamic responses will be developed. New computational capabilities will be developed to predict the stability boundaries of complex aircraft configurations, and highly instrumented models will be tested to validate prediction methods and provide data that will facilitate understanding of the physics of the associated flows.

Development of structures and materials technologies for hypersonic aircraft strives for high strength, light weight, and resistance to extreme aerothermodynamic and acoustic environments. Materials R&D activities have produced a substantial database on titanium aluminides, metal-matrix composites, and refractory composites. Theoretical chemistry and laboratory experiments are answering questions concerning processing and fabrication as well as the compatibility of materials with hydrogen fuel.

Space Research and Technology

Space research in advanced materials and processing focuses on synthesis and development of space-durable materials for launch systems, space platforms, space science instruments, spacecraft, and re-entry and high-speed flight vehicles. Materials of special interest include carbon-carbon composites, ceramics, and ceramic-matrix composites for lightweight thermal protection systems, and advanced metallic alloys, metal-matrix composites, and polymer-matrix composites for lightweight cryogenic tanks. Special emphasis is placed on the study of space environmental effects on materials.

The Space Science and Applications program is developing thermoelectric materials, photovoltaic cells, and photovoltaic arrays to reduce the weight and improve the efficiency of nuclear and solar power sources, both for future planetary science missions and for solar electric propulsion systems for orbit transfer and interplanetary exploration.

High-efficiency, lightweight, rugged, radiation-resistant solar cells must be developed if NASA is to achieve its goals of 300 watts per kilogram (kg) for a deployable planar array and 300 watts per square meter at 100 watts/kg in concentrator arrays. Researchers at the Lewis Research Center are focusing on indium phosphide and gallium arsenide solar cells, while researchers at JPL are developing an ultra-lightweight, high-performance, deployable photovoltaic array suitable for a broad range of long-term NASA space applications in the 21st century.

Advances needed for future space transportation include highly efficient vehicle structures, lightweight and highly durable thermal-protection materials, and lightweight and long-life cryogenic tankage. Benefit studies indicate that significant weight and cost savings can be realized based on recent accomplishments in low-density aluminum materials and processing technologies. Research in cryogenic tankage focuses on development of optimal cryotank structures through superplastic forming and resistance spot-welding of aluminum-lithium alloys. Benefit studies indicate that weight reductions of 20 percent and cost reductions of 25 percent are attainable.

Reusable thermal protection system materials are being developed to withstand temperatures of 2200°C and up. These materials include diborides and carbides of titanium, zirconium, and hafnium. The new rigid tile materials have been flight tested several times on the space shuttle and another vehicle during 1994 and 1995. The new ablators identified for applications approaching the 2750°C regime are formulated from ceramic and organic components. One ablator has been chosen to fly for the first time in a heat shield on the Mars Pathfinder entry probe, which will arrive at Mars in 1997.

Studies on space environmental effects on materials were carried out in the Long Duration Exposure Facility (LDEF), which was deployed by the space shuttle and picked up several years later. The results of these studies are playing a significant role in design of the International Space Station. The LDEF data have enabled the development of improved materials and coatings and aided in the choice of materials for space station construction and shielding. In addition, to enhance the power capability of the space station via solar dynamic power, new materials for thermal energy storage are being identified and tested. New materials and design techniques could enable the construction of lightweight concentrators and heat receivers for the solar dynamic modules now under development.

The Microgravity Science and Applications program sponsors basic and applied research requiring low-gravity conditions. In space, the absence of gravity-induced phenomena, such as buoyancy-driven convection, sedimentation, and hydrostatic pressure, provides a unique opportunity to study many physical processes and materials. Topics of study include fluid phenomena, combustion, materials science, and protein crystal growth.

Thousands of Material Specimens Studied in Space

Data collected by NASA on space environmental effects on materials have enabled the development of improved coatings and structures as design options for the International Space Station. The data were collected aboard the Long Duration Exposure Facility, which was deployed into space by the space shuttle and retrieved on a later mission. More than 10,000 specimens of structural, thermal protection, and solar cell materials were monitored, with the research focusing on the effects of exposure to impacts of micrometeoroids and space debris and the synergistic effects of atomic oxygen, ultraviolet and particle radiation, and contamination. The data have led to improved materials and coatings for durable space station construction and shielding applications.

Major Research Facilities and Centers of Excellence

Ames Research Center
Moffett Field, CA

Dryden Flight Research Center
Edwards Air Force Base, CA

Langley Research Center
Hampton, VA
Aeronautics Center of Excellence for
Airframe Systems

Lewis Research Center
Cleveland, OH
Aeronautics Center of Excellence for
Airbreathing Propulsion Systems

Marshall Space Flight Center
Huntsville, AL

Centers for the Commercial Development of Space focusing on materials:

> Consortium for Materials
> Development in Space
> The University of Alabama, Huntsville
> Huntsville, AL

> Space Vacuum Epitaxy Center
> University of Houston
> Houston, TX

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mirror assemblies).

National Science Foundation

NSF Primary Organizational Units Sponsoring R&D Programs in Materials Science and Technology:

Directorate for Mathematical and Physical Sciences
- Division of Materials Research
- Division of Chemistry
- Division of Physics
- Division of Mathematical Sciences

Directorate for Engineering
- Division of Electrical and Communications Systems
- Division of Chemical and Transport Systems
- Division of Civil and Mechanical Systems
- Division of Design, Manufacture and Industrial Innovation
- Division of Bioengineering and Environmental Systems
- Division of Engineering Education and Centers

Directorate for Computer and Information Science and Engineering

Directorate for Biological Sciences

Directorate for Geosciences

Directorate for Education and Human Resources

Division of International Programs

Overview of Materials R&D Activities

The mission of the National Science Foundation (NSF), in the broad context of Federal materials R&D activities, is to support research and education with the following overall goals: to enhance the fundamental understanding of materials, to develop appropriate partnerships with universities and industry, and to provide interdisciplinary education and training to prepare future scientists and engineers for careers in academia, government, and industry.

NSF supports both experimental and theoretical research, with three primary objectives: to synthesize novel materials with desirable properties, to advance fundamental understanding of the behavior and properties of materials, and to develop processes for producing, modifying, and shaping materials. This research lead to identification and development of new materials and improved understanding of interrelationships among synthesis and processing of materials, their structure and composition, and their properties and performance at the atomic, molecular, microscopic, and macroscopic scales.

The NSF materials R&D program is crucial to the timely development of many technologies. For example, advances in manufacturing technologies depend on new and improved materials and materials processing methods; modern civil infrastructure systems require improved structural materials; biotechnology relies on novel biomaterials and bioprocessing techniques; next-generation computers and information storage, display, and transmission devices will result from new electronic and photonic materials; and environmental concerns are addressed by the development of benign materials.

In January 1995, NSF convened a panel of industrial R&D leaders and university and government laboratory scientists and engineers to identify areas of opportunity in materials science and engineering. The areas selected include bio- and biomolecular materials, materials for the information age, and special materials (i.e., carbon-based materials, two-dimensional composites, and electrolytes). The current and potential future impact of these research areas reaffirms the key enabling role of advanced materials and processes for a broad range of industrial innovations and advances in quality of life.

NSF supports R&D through a variety of funding modes: grants to individuals and small groups of investigators, support for centers, and support for National User Facilities open to both public and private investigators. Support also is provided for state-of-the-art instrumentation and instrument development. Although most of the funding goes to individuals and small groups, many research problems are so complex and instrument-intensive that collaborative efforts are required to make significant and rapid progress. NSF also fosters interagency collaborations and promotes materials-related activities through university-industry-government consortia.

The organizational units providing most of the support for materials R&D include the divisions of Materials Research; Chemistry; Electrical and Communications Systems; Chemical and Transport Systems; Civil and Mechanical Systems; Design, Manufacture, and Industrial Innovation; Bioengineering and Environmental Systems; and Engineering Education and Centers. Additional support, through the use of NSF supercomputer centers, comes from the Directorate for Computer and Information Science and Engineering. Support also is provided by the Division of Physics, the Division of Mathematical Sciences, the Directorate for Biological Sciences, and the Directorate for Geosciences.

In addition, support for graduate fellowships and Minority Research Centers of Excellence is provided by the Directorate for Education and Human Resources. The Division of International Programs, the Experimental Program to Stimulate Competitive Research, and the Office of Science and Technology Infrastructure also provide support for materials science and engineering.

NSF-supported materials research programs focus primarily on the synthesis of new materials, understanding of fundamental principles, novel and creative approaches to materials processing, the application of basic knowledge of materials, and the training of future scientists and engineers, generally through academic research. These activities are pursued in each of four categories of research: materials chemistry, materials physics, materials engineering, and biomolecular materials.

Materials R&D Base Programs

Materials Chemistry

Research in materials chemistry emphasizes synthesis, characterization, and structure-property relationships of materials at the molecular level. Special emphasis is placed on the synthesis of new materials, improvements in existing classes of materials with superior properties, and the application of functional materials with special regard to environmental impact. These activities are supported by the divisions of Chemistry, Materials Research, Earth Sciences, and Chemical and Transport Systems.

Inorganic chemistry projects cover a variety of topics, including synthetic routes to new inorganic and mesophase materials, design and synthesis of molecular precursors for chemical vapor deposition of solid state materials, reactive intermediates in semiconductor deposition, synthesis of inorganic polymers and polynuclear metal clusters, and sol-gel preparation of metal-containing glasses. Research focuses on characterization of new materials with interesting electronic, optical, magnetic, and chemical behavior.

Research in solid-state chemistry emphasizes the synthesis, characterization, and structure-property relationships of solid, liquid, and mesophase materials and provides fundamental knowledge relevant to the processing and optimization of functional materials by chemical means for advanced technologies. This research includes studies of the relationships of chemical composition, structure, and defects to properties such as ionic and electronic conductivity, mass transport, and absorptive, magnetic, optical and electronic behavior. Fundamental relationships are explored between bulk, surface, interface and defect structures and properties such as chemisorption, transport, and chemical reactivity. Topic areas include ionic and molecular solids, liquid crystals, quasi-low-dimensional materials, surface and interface chemistry, and ultra-fast chemical, electronic, and optical phenomena in solid-state materials. Theoretical investigations cover a broad range of issues relating to solid-state chemical synthesis by design and structure-property relationships exhibited by solid-state, liquid, and mesophase materials.

Studies in analytical and surface chemistry address the chemistry of materials interfaces involving semiconductors, metals, and gas-solid interfaces; surface mechanisms in vapor

Basic Research Yields New Material For Cooling Applications

A new class of materials with a broad range of potential cooling applications has been invented as a result of NSF-supported basic research in solid state chemistry, a field devoted to identification of novel compositions and structures of matter with extraordinary electrical and optical properties. These highly efficient thermoelectric materials, composed of alkali metals, bismuth, and tellurium, were synthesized by researchers at Michigan State University and Northwestern University using a low-temperature molten salt technique. Such techniques enable the synthesis of more complex materials structures than is possible with traditional high-temperature methods. The complex structure and unique chemical composition of these new bismuth tellurides gives rise to very low thermal conductivity and very high thermoelectric power and electrical conductivity, the key properties for thermoelectric applications, in which the electrical current serves as a cooling agent or the temperature gradient provides power. Thermoelectric materials already are used in space applications, but improved materials may find wider usage in environmentally friendly refrigeration and air conditioning, cooling of electronic devices and biological samples, waste heat recovery and conversion to electric power, and thermal suits for diving and fire fighting.

deposition of metals, diamond, and semiconductors; and the mechanisms of oxidation and corrosion of materials. In addition, effort is devoted to development of surface and interface characterization methods, such as scanning probe microscopy and electron paramagnetic resonance imaging.

Research in polymers and organic chemistry covers synthetic macromolecules, including fullerenes and other carbon allotropes; organized molecular assemblies; and the complexities resulting from their large size (e.g., molecular arrangements in amorphous, crystalline, and liquid-crystalline polymers) and in their mixtures. Topics include the synthesis of new polymers of high molecular weight and precisely defined structure, as well as unconventional methods of polymerization; characterization of the chemical and physical structure of polymers using state-of-the-art techniques; compatibility and phase relations in polymer blends; polymeric networks; macromolecular chain dynamics and relaxations; molecular origins of electronic and optical properties in organic macromolecules; and fundamental polymer and surface science in organic-matrix composites.

Other concepts under study include molecular photosynthetic mimics, nanostructured materials, synthesis of conducting polymers, organic superconductors and ferromagnets, molecular electronic devices, reactions in layered and constrained media, and optical activity in helical polymers.

Research in experimental and computational physical chemistry focuses on electronic structure of semiconductor clusters, theory of micelles and surfactant films, kinetic theory of polymer solutions, chemical and neural networks, molecular dynamics in solids, and laser- and plasma-induced chemistry at surfaces.

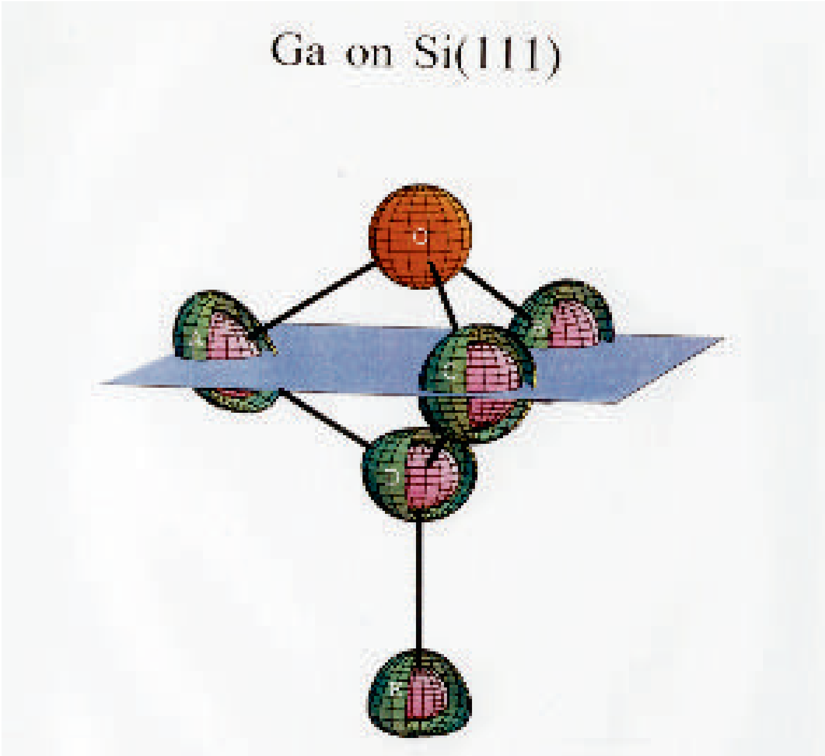
Materials Physics

Materials physics activities seek to understand the basic physical behavior of solids and other forms of condensed matter. Projects include experimental and theoretical research on metals, polymers, biomolecular materials, semiconductors, and insulators in the crystalline, amorphous, and various other states of atomic order.

Research is carried out on new phenomena and new states of matter. Important activities include the development of new and improved experimental techniques. Such projects extend to the development of methods for fabricating new materials and artificially structured materials. Phenomena and properties studied include phase transitions; quantum effects in nanostructures; electronic, magnetic, and lattice structure of solids; elementary excitations (e.g. electronic, spin, plasma, and lattice excitations); properties of clusters; and transport and optical properties of condensed matter.

An area of growing interest involves the measurement and description of nonlinear phenomena in many condensed matter systems. Topics include surfaces, thin films, optical nonlinearities in polymers and organic materials, superconductivity and magnetism, superfluid properties of helium, electronic properties of surfaces and interfaces, microstructures, and phenomena pertaining to systems of reduced dimensionality and reduced crystalline perfection. An important research area is condensed matter that requires extreme conditions, such as low or ultra-low temperature, ultra-high pressure, and high magnetic fields.

Theoretical investigations cover the broad range of fundamental issues in condensed matter sciences -- in particular, the structure and properties of metals, semiconductors, ceramics, polymers, complex fluids, quantum fluids, and other phases of condensed matter. This basic research makes use of analytical theory, phenomenological modeling, and numerical simulation to understand phenomena from the atomic to the microstructural and mesoscopic levels of condensed matter and materials. Topics of interest include surface and interfacial phenomena; crystal growth and thin-film epitaxy; systems far from equilibrium; phase transitions and critical phenomena; superconductivity and superfluidity; electronic structure calculations; nonlinear and dynamical phenomena; predictive capabilities for structure-property relationships; lattice dynamics; defects and their interactions; elementary excitations and their interactions; electronic, optical, and magnetic properties; and kinetics and transport phenomena.



Scanned energy photo-electron holographic imaging represents a major advance in surface science, providing ultra-high resolution three-dimensional images of finite regions within the atomic structure. The figure shows a detailed atomistic view of an adsorbate (gallium atom in red) - substrate (silicon atoms in green) interface. The holographic technique, which employs synchrotron X-rays, allows high-resolution measurement of dimensions less than that of individual atoms. This research was carried out by investigators from Montana State University using the facilities at the Synchrotron Radiation Center at the University of Wisconsin, Madison.

Materials Engineering

Engineering R&D, supported primarily by the Engineering Directorate and the Division of Materials Research, includes activities ranging from development of chemical processes for reliable volume production of high-quality new materials, to the development of mechanical processes that transform materials systems during manufacturing into preferred solid shapes, for use as parts of finished products with superior performance (e.g., increased safety). The objectives are to increase knowledge and predictive capabilities related to the effects of chemical and physical behavior, processing, and microstructure on the properties and performance of these materials systems, and to expand understanding of environmental influences, including those affecting the safety of structures made of new materials.

In ceramics, research focuses on solid-state processing, plasma processing, powder processing, ion implantation, mechanical behavior of ceramics and ceramic composites, computational modeling of mechanical behavior, behavior under complex stress states and extreme environments, chemical stability, reactivity, and kinetics, defect structures, and transport properties. Life-cycle costs are prominent considerations.

Research in electronic materials covers the electronic, dielectric, and optical behavior of inorganic and organic materials systems, semiconductors, superconductors, insulators, and nonlinear optical materials; synthesis and processing of thin films, heteroepitaxial layers, nanostructures, and superlattice structures; novel processing routes and precursors; computational modeling of advanced processing techniques; and characterization of electronic and optical behavior of defects.

Studies of metal systems include the broad areas of physical and mechanical metallurgy. Current topics include phase transformations, thermodynamics and phase equilibria, microstructural characterization and morphology, fundamentals of solidification, nonequilibrium and amorphous materials, surface structure, microstructure, and properties, interfaces and grain boundary structure, corrosion and oxidation, deformation and fracture, surface and subsurface modifications of metals and composites, and properties and performance of metals and composites.

Polymer and composites engineering is concerned with improving processes for preparing and shaping such materials systems to optimize their mechanical and other properties. Topics under study include extrusion, injection molding, and casting of thermoplastics, thermosets, or elastomers for preparation of sheets, films, fibers, or membranes. Additional concerns include automation of layup processes for polymer-matrix composites containing high-strength fibers, interfacial bonding and adhesion, and the chemistry of thermosetting reactions. Increasing attention is being devoted to deterioration and associated loss of safety, and total life-cycle costs. Of special interest are materials properties associated with prevention of damage in earthquakes and other violent mechanical loading.

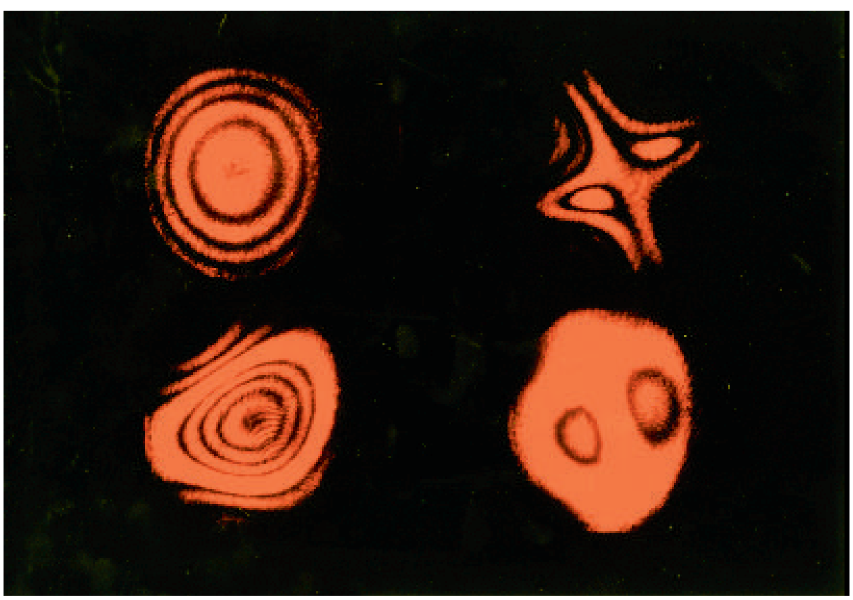
Studies of chemical reaction processes provide means of integrating transport phenomena with kinetics and catalysis in the design of chemical reactors to manufacture new and novel materials. Processes under study include metal-organic chemical vapor deposition and plasma-initiated reactions, processing of ceramics such as silicon carbide, and reaction polymerization.

Fluid and particulate processing research focuses on fluids and micrometer and submicrometer particles. Examples of processes under study are fluidized bed reactions, two-phase metal flows, liquid and solid aerosols, droplet formation, and vapor deposition. Thermal systems studies address the effects of heat transport phenomena in controlling the composition, crystal structure, microstructure, and morphology of materials. Combustion and thermal plasma processes are applied in studies of direct synthesis of densified materials and powders through exothermic processes. Interfacial, transport, and separations research emphasizes the synthesis and processing of novel materials to be used in separation and purification devices (e.g., polymeric and ceramic membranes, and electrically controlled membranes). Thin-film layer and coating processes also are examined.

Several programs bridge the materials and device fields in the synthesis and processing of new and emerging materials systems for electronic and photonic technologies. These programs address solid state and microstructures (i.e., electronics); quantum electronics, waves, and beams (i.e., photonics); and communications and computational systems. Projects include design, simulation, modeling, processing, and characterization of unique electronic behavior of semiconductor and semi-insulator materials; monolithic integration of electronic and photonic functions on a chip novel nonlinear optical materials for photonic devices and systems, such as optical information storage and processing; optical interconnects and data communications; nanolithographic mask materials, pattern generation, and transfer; etching processes for X-ray and focused ion beams; superconducting thin films and hybrid devices; isotopic-enriched semiconductors for microelectronics; high-density magneto-optic storage media; materials, device, and fabrication design for microelectromechanical systems; nonvolatile semiconductor memory devices; integration of advanced sensors, process models and adaptive control methodologies in materials processing; computational simulation of devices and processing; and sub-picosecond characterization and measurement tools for dynamic processes in materials and devices.

Research in mechanics and materials supports theoretical, experimental, and computational studies of the deformation, fatigue, and fracture behavior of solid materials, including composites that account for the underlying phase, defect, and microstructural state and its origin, transformation, and evolution. Research topics include design and realization of materials with improved physical and mechanical properties, constitutive modeling for inelastic deformation and failure under multi-axial static and dynamic loadings, and modeling and computer simulation of thermo-mechanical aspects of materials processing involving large strains and high strain rates, as well as wide temperature variations. Deterioration in adverse environments is of considerable interest.

Materials processing and manufacturing research is concerned with development of economically competitive and environmentally acceptable methods for processing materials and manufacturing products



A researcher at the University of Arizona has discovered photo-refractive polymer films having extremely high diffraction characteristics that can serve as both the read and write holographic optical media in optical information storage applications. The figure shows mode patterns of a circular vibrating membrane obtained by time-average interferometry.

with engineered microstructures and properties. Research areas include processing and net-shape manufacturing of components and structures made from advanced materials such as composites; and modeling, simulation, and control of unit manufacturing processes, ranging from established processes such as casting, pressing, and extrusion to vapor- and plasma-assisted processes and directed energy-beam processing (including surface modifications) of advanced materials. Support is provided for novel processes, such as prototype manufacturing, that eliminate several manufacturing steps and dramatically cut inventory costs and market cycle time.

The Strategic Manufacturing Initiative is an engineering program that includes activities in computer-aided analysis of deformation processing, solid free-form fabrication of ceramics, materials characteristics in wear and fracture, sensor models and theory, materials processing, machining of optical parts, and electronic packaging.

Biomaterials R&D Offers Promise of Innovative Healing Aids

A multitude of recent advances in NSF-supported biomaterials research is hastening the development of innovative healing aids with high commercial value. For example, researchers at Georgia Institute of Technology, California Institute of Technology, and Massachusetts Institute of Technology (MIT) are working with physicians and biological specialists to develop polymer composites for patching wounds, biocompatible casings for cell transplants, scaffolds that guide and encourage cells to form tissue, bioreactors for large-scale production of therapeutic cells, and experimental and theoretical models that predict behavior of these materials in vivo. Materials also have been developed that block unwanted reactions between transplanted cells and host tissue to help prevent scarring during healing. Closest to the commercialization stage is an MIT project in which the synthesis of a copolymer of lactic acid and lysine has resulted in a polymeric material that allows the adhesion of biological cells to the copolymer. Because the human body accepts such cells (while it might reject the overlying synthetic material), this breakthrough makes possible the development of inexpensive multilayer materials that can promote healing, act as artificial skin, or temporarily replace connective tissue until the body can produce natural tissue to complete the healing process. Companies are being sought to develop commercial products based on the new polymeric material.

Biomolecular Materials

Biomolecular materials exhibit useful and often novel properties of a chemical, structural, mechanical, electronic, or optical nature. These materials, produced naturally or synthetically, may use or mimic biological functions in the production, alteration, or degradation of substances; they may have particular structural, protective, adhesive, or fluid properties; or they may act as sensor transducers or molecular motors. Pathways for synthesis can be modified by genetic or other means to produce materials with desired molecular architectures, structures, or properties; to enhance processing steps for purification and separation; or to promote self-assembly of arrays or polymers.

Studies across the whole range of biology are contributing to biomolecular materials research. Molecular and cellular biosciences may uncover potentially useful models for synthetic materials. Neuroscience and physiology may reveal principles for microchemical signaling, receptors, and memory storage, and for polyfunctional materials such as bone, wood or skin. Ecological and environmental studies may clarify the nature and diversity of materials processing and recycling approaches on large scales.

A silking apparatus permits separation of dragline silk from other silks and pulls it onto a rotating white drum. A postdoctoral student from Cornell University is holding one of the golden, orb-weaving spiders that produce the dragline silk.

Spider Silk May Offer Super Strength

Dragline silk from the orb-weaving spider is one of the most promising biomolecular materials due to its great strength and flexibility -- greater even than Kevlar®, the lightweight fiber used to reinforce bullet-proof helmets. Also attractive is the environmentally friendly process used to make the silk, which the spider spins from a water-based solution. (Kevlar, by contrast, is made from concentrated sulfuric acid.) Intrigued by this Central American spider, which actually makes seven different types of silk, Professor Lynn Jelinski of Cornell University has a vision that high-performance, renewable, silk-like polymers eventually can be made using the tools of biotechnology. That is, scientists eventually will synthesize the key spider genes and insert them in plants, which then would express the protein polymers. In initial steps toward realizing this vision, Dr. Jelinski is trying to determine how the spider produces the dragline silk. She also is using solid-state nuclear magnetic resonance techniques and the Cornell High Energy Synchrotron Source, an NSF-supported National User Facility, to characterize the physical properties of the material, which eventually might be used in products ranging from bullet-proof vests to automobile tires.

Following are examples of research areas in which advances seem likely in the near future:

Biologically inspired materials. Topics include bioadhesives, synthetic wood and bone, molecular motors, microspheres as delivery vehicles, biomembranes that exploit surface interactions or separation functions, and biopolymers of exceptional elasticity or strength.

Molecular self-assembled materials. These materials can form membranes, microspheres, polymer chains, tubes, or sheets.

Molecular-scale synthesis and processing. Topics include biochemical modulators, such as enzymes, growth factors, and molecules for cellular communication; processing, synthesis, and conversion under benign conditions; processes used by "extremophile" organisms at conditions of high temperatures, pressures, or acidity; and environmental cleanup biomaterials, such as molecules that sequester heavy metals.

Combinatorial approaches. Computational strategies are used to develop efficient screening methods for revealing novel properties of both natural and synthetic biomaterials.

Hierarchical structures. Topics include biologically derived sensors that detect optical, chemical, or mechanical cues as parts of measurement devices; arrays of biomolecular sensors for use in information storage or multisensory probes; self-correction mechanisms for multi-component systems; and combinations of nanofabrication techniques or microelectronics technology with biological compounds for use as aids in fabrication or as semiconductors.

Synthesis of polymers designed by living organisms. Topics include the use of genetically engineered plants or microorganisms for bulk production of artificial polymers, development of protective waxes or oils with particular properties for lubrication or protection, and development of bioadhesives and detergents.

Engineering of biomaterials. New synthetic materials are being developed with improved biological compatibility and longevity. Research focuses on evaluating alternative materials, biochemical and biomechanical issues, and stability and self-correction mechanisms.

Engineered tissues. An emerging area of research is tissue engineering, which is the application of fundamental engineering and the life sciences to the understanding of living mammalian tissues and the synthesis and use of biological substitutes for these tissues. Potential applications include living tissue equivalents of skin, bone, blood vessels, liver cells, pancreatic cells, cartilage, nerve, bone marrow, and blood components (i.e., red cells, platelets, white cells).

Other Materials Science and Engineering Programs

The Division of Mathematical Sciences and the Directorate for Computer and Information Science and Engineering (through the NSF supercomputer centers) address materials modeling and simulation.

Geochemistry and geophysics research in the Division of Earth Sciences is concerned with the properties and behavior of materials at extreme temperatures and pressures. The characterization and analysis of geologic materials at extreme temperatures and pressures often coincide with materials research programs conducted elsewhere within NSF. Instrumentation developed for the study of natural geologic materials is often very useful in the study of manmade materials.

The Division of International Programs supports collaborative projects involving individual U.S. and foreign scientists and engineers. These activities span the full range of projects supported by NSF, including the roughly 160 concerned with materials research.

The Small Business Innovation Research (SBIR) Program offers opportunity and incentive for small, creative firms engaged in engineering, science, education, or technology to conduct innovative, high-risk research on important scientific and technological problems with commercial potential. A relatively large percentage of the NSF awards under this program focus on materials research.

The Grant Opportunities for Academic Liaison with Industry (GOALI) Initiative and the Small Business Technology Transfer (STTR) Program constitute the Industry/University Liaison Program. GOALI provides opportunities for direct linkages between academic researchers and industry. The STTR reinforces the SBIR Program by linking entrepreneurs to the academic research community to encourage commercialization of government-funded research by the private sector.

Major Laboratories, Groups, and Centers

NSF supports a variety of research laboratories, groups, and centers. Among these are National User Facilities, where unique capabilities are provided for the entire scientific community. These facilities are described later in this report, (National User Facilities). Many additional facilities are provided at various national laboratories serving NSF-supported scientists and engineers. The research conducted by users of NSF-supported facilities often is supported by other Federal agencies.

The Materials Research Science and Engineering Centers (MRSEC) program supports interdisciplinary research addressing fundamental problems of intellectual and strategic importance. The centers have strong links to industry and other sectors, provide support for shared experimental facilities, and support educational outreach to other institutions. The MRSEC program was established in 1994 and supersedes the Materials Research Laboratories (MRL) and Groups (MRG) programs.

The Division of Materials Research currently supports 11 MRSECs, 5 MRLs, and 13 MRGs. (Ongoing MRL and MRG awards have been transferred to the new program and will compete in it as they expire.) The costs of the MRSECs are shared with the private sector. Total funding from outside sources is more than twice the NSF contribution. In 1994 the MRSECs had approximately 200 partners from industry, and more than 2,700 researchers were associated with MRSEC facilities.

MRSECs include broad-based centers with diverse research agendas as well as those with more focused scientific programs. The former group, including the existing MRLs, feature research at the cutting edge of materials science and engineering in areas such as polymers and biomolecular materials, electronic and photonic nanostructures, superconducting and superhard materials, oxide surfaces and magnetic systems, and materials design for manufacturing. The more focused centers, including the existing MRGs, emphasize specific areas of scientific and strategic importance such as magnetic materials for information storage, sensors for automobile control and diagnostics, and enabling technologies for the manufacture of electronic materials.

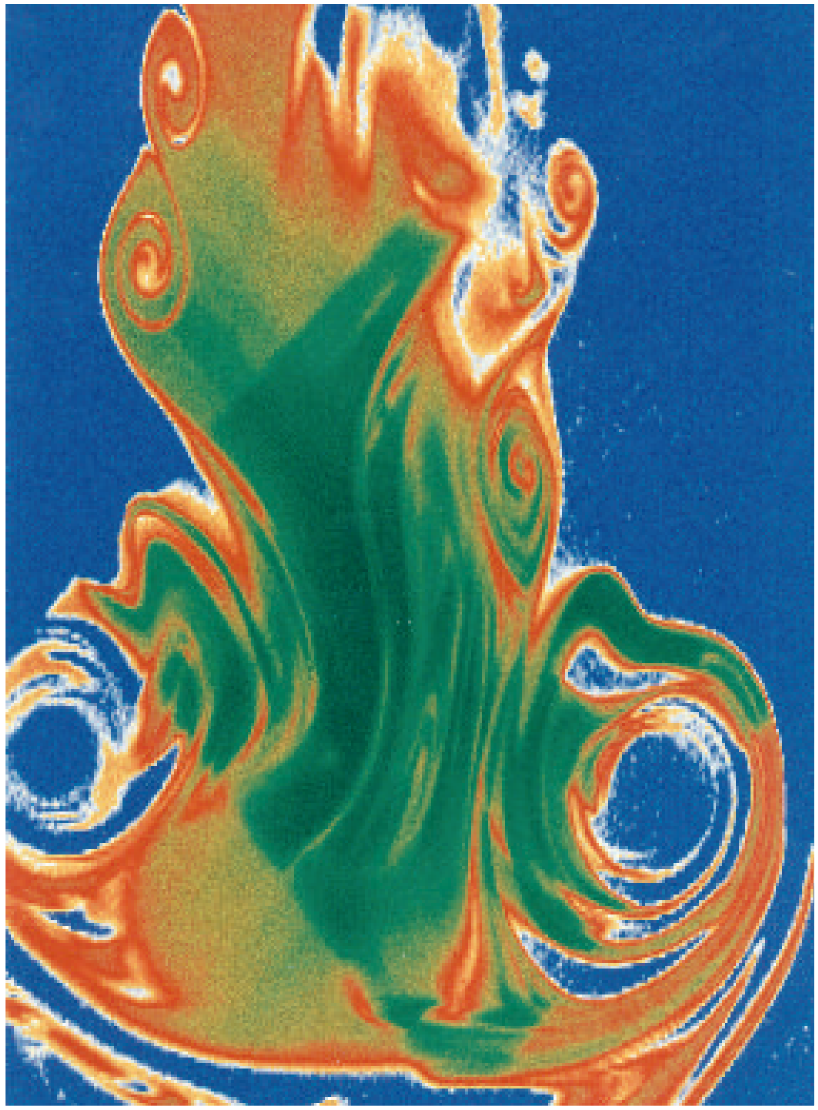
Ultra-sensitive Magnetic Sensor Developed

A novel magnetic field sensor capable of measuring very weak magnetic fields -- levels as low as one millionth of the Earth's magnetic field -- has been demonstrated by the Materials Research Science and Engineering Center at the University of California, San Diego, in collaboration with Eastman Kodak Co. The sensor is very simple and economical, consisting of a wire, five-thousandths of an inch in diameter, on which a very thin magnetic field is electroplated. When a high-frequency alternating current is passed through the wire, the electrical resistance level changes enormously in the presence of very small magnetic film. The Earth's tiny magnetic field changes the resistance more than tenfold. Because such resistance can be measured very accurately, the sensor has extraordinary sensitivity, making it possible to enhance the performance of many types of technologies at little additional cost. The phenomenon has been labeled Giant Magneto-Impedance, or GMI. Among the numerous potential applications of GMI are high-density magnetic information storage, brain wave mapping, military sensors, and tachometers of all types.

Recent research highlights include a breakthrough in an alternative design of vastly improved semiconductor electro-optical components, feasibility studies for ultra-small lasers that would improve on-chip sensing and diagnosis significantly, fundamental discoveries in the way liquid drops form and develop, and basic advances in understanding of high-temperature superconductors that are likely to lead to useful applications.

The Science and Technology Centers (STCs) were established to exploit opportunities where the complexity of the problems requires broad-scale, long-term research and also may require special facilities or collaborative relationships across disciplines that can best be provided by campus-based research centers. Each STC has a major research theme and may involve more than one institution. The STCs are encouraged to reach out to industry and national laboratories to undertake a broad range of activities. The STCs also seek to involve pre-college and undergraduate students and teachers, to draw them into science and engineering.

NSF established 11 STCs in 1989 and 14 more in 1991. Nine of these centers emphasize materials. These programs focus on superconductivity; quantum structures in electronic materials; advanced cement-based materials; polymer adhesives and composites; advanced liquid-crystalline optical materials; photo-induced charge transfer; the synthesis, growth, and analysis of electronic materials; and high-pressure research.



The illustration shows a false-color image of a turbulent fluid one millionth of a second after illumination by an optical laser. The laser is used as a noninvasive tool to tag the instantaneous position of each individual fluid molecule. The image is of much higher spatial resolution and is obtained in a much shorter time than was heretofore possible. These results came about from a collaboration of experts in chemical materials synthesis, imaging science, and internal combustion engineering. The discoveries bear on a wide range of fundamental and applied problems, including the effort to develop high-efficiency, low-emissions automobile engines, under investigation by the Materials Research Science and Engineering Center at Michigan State University.

Engineering Research Centers (ERCs) support cross-disciplinary centers where academe and industry join to bring engineering and scientific disciplines together to focus on the next generation of technological advances in engineering systems. These centers address major areas of technology that are the foundation for the competitiveness of U.S. industry. The ERCs are designed to catalyze a new research and educational culture in academe, where disciplines mix, research and education are integrated, and academic and industrial perspectives on research, education, and technology blend together. The research programs are a mixture of fundamental inquiries exploring the underlying scientific and engineering principles in a thematic area and a spectrum of other activities through to applications in testbeds.

The ERC program also aims to educate a new generation of engineers in a cross-disciplinary, systems-integration approach to problem solving. The centers provide an educational environment where the cross-disciplinary, systems perspective on research becomes integrated into the educational process. ERCs involve undergraduate and graduate students in integrated, cross-disciplinary research teams. The close association with industrial partners helps cultivate a new breed of students who are both capable of integrating the knowledge needed to advance technology and familiar with industrial practices.

Each ERC is established as a three-way partnership involving academia, industry, and the NSF, often with participation of state and other Federal agencies. Of the 21 centers, eight focus on materials, addressing topics such as advanced electronic materials processing, plasma-aided manufacturing, interfacial engineering of electronic materials, net-shape manufacturing, "intelligent" manufacturing systems, compound semiconductor microelectronics, and advanced electronic packaging.

NSF also supports Industry/University Cooperative Research Centers, although NSF investment diminishes over time as the bulk of funding responsibility shifts to industry. Of the 55 centers now receiving NSF support, 22 are oriented toward materials research involving processing and characterization of glass, thin films, and interfaces; sensors and actuators; processing of metals, alloys, polymers and blends; ceramic devices; dielectrics; nondestructive evaluation; composites; welding; and defects.

In 1991, NSF and state governments joined to develop an initiative to support with industry a number of State/Industry/University Cooperative Research Centers (S/I/UCRCs). These centers focus on engineering and science topics and address the technology development interests of industrial firms whose concerns are relevant to the economic development opportunities of the centers' home states. The purpose of this joint initiative is to coordinate investments by NSF, the states, and industry in centers that undertake research and other activities that foster local economic development and the competitiveness of U.S. industry.

NSF and the states provide base funding in equal amounts, which must be at least matched by industry. The S/I/UCRCs seek innovative means to transfer technology in order to expand the technical knowhow of local businesses in the center's fields of research. Six S/I/UCRCs were started in 1991, and four more were added in 1992. Five of the current centers address materials topics, including low-cost, high-speed polymer composites processing; computer-aided life-cycle engineering of electronic packaging; integrated electronics packaging engineering; molecular and microstructure of composites; and enhancement of the biology/biomaterials interface.

The Materials Science Research Center of Excellence at Howard University, an NSF-supported Minority Research Center of Excellence) is focusing on the development of wide bandgap semiconductors such as silicon carbide. Successful exploitation of these materials would have a significant effect on display, avionics, and automotive technologies.

Finally, seven Minority Research Centers of Excellence focus on optical, electronic, and biomolecular materials.

NSF Contacts

The NSF units listed below are the initial contacts for inquiries. The addresses are: Appropriate Unit, National Science Foundation, 4201 Wilson Boulevard, Arlington, VA 22230.

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Chemical and Transport Systems (ENG)
(703) 306-1371

Civil and Mechanical Systems (ENG)
(703) 306-1360

Design, Manufacture, and Industrial Innovation (ENG)
(703) 306-1330

Electrical and Communications Systems (ENG)
(703) 306-1339

Engineering Education and Centers (ENG)
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Molecular and Cellular Biosciences (BIO)
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Integrative Biology and Neuroscience (BIO)
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Biological Instrumentation and Resources (BIO)
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Earth Sciences (GEO)
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Computer and Information Science and Engineering (CISE)
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Office of Science and Technology Infrastructure (OSTI)
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National User Facilities

Contacts for National User Facilities and Supercomputing Centers are listed in Chapter 4, National User Facilities.

United States Department of Agriculture

USDA Primary Organizational Units Sponsoring R&D Programs in Materials Science and Technology:

Forest Service (FS)

Agricultural Research Service (ARS)

Cooperative State Research, Education and Extension Service (CSREES)

Economic Research Service (ERS)
Office of Energy and New Uses (OENU)

Overview of Materials R&D Activities

The materials R&D conducted by the U.S. Department of Agriculture (USDA) addresses the use of renewable nonfood agricultural and forestry materials and their derivatives in industrial and manufacturing processes and products. Four USDA agencies and one center support R&D activities within the MatTec framework.

Over the last several years, advanced materials have assumed elevated importance within USDA as part of the New Uses for Farm and Forest Products program. This program, initiated to accelerate development of new industrial uses for agricultural and forestry materials, requires close cooperation with industry throughout the development and testing of products and materials. Also, to increase USDA's involvement in the development of new materials, the Office of Energy (part of the Economic Research Service) recently was renamed the Office of Energy and New Uses and given an expanded mission that includes analyzing new policies, strategies, and regulations concerning the feasibility of new uses for agricultural products.

Two agencies conduct in-house R&D. The Forest Service (FS) is responsible for providing national leadership in forestry and forestry-related issues. Its research arm develops and communicates scientific information and technology needed to protect, manage, and use the Nation's 1.6 billion acres of forest and rangeland to meet U.S. needs and contribute to the needs of the international community. The Agricultural Research Service (ARS) develops the new knowledge and technology needed to solve a broad range of technical and agricultural problems of high national priority. As part of its work, the ARS conducts research on the production and characterization of biobased materials.

The Cooperative State Research, Education, and Extension Service (CSREES), USDA's principal link to academia, supports extramural activities focusing on development and commercialization of renewable, nonfood crops and products. The Economic Research Service (ERS) analyzes the strategies for and feasibility of new uses for agricultural products. The Alternative Agricultural Research and Commercialization (AARC) Center supports private-sector R&D designed to accelerate development and commercialization of industrial nonfood, nonfeed products manufactured from farm and forestry materials.

USDA's Super-Absorbent Material Soaks Up Business

A super-absorbent material discovered by USDA researchers in the 1970s has led to development of a series of new products now made by companies worldwide. The material was discovered by chemists at what is now the National Center for Agricultural Utilization Research in Illinois, who strung together long chains of acrylonitrile, a major petrochemical, on top of starch molecules, and then split the product apart and added water. The researchers observed that the resulting material could absorb many hundreds of times -- even a thousand times -- its own weight in water and still maintain a solid, jello-like consistency. The product quickly intrigued the chemical products industry and a number of companies worldwide now manufacture products based on the principles of the material. The materials are used as absorbent additives in products such as disposable diapers, bandages, ulcers and wound treatments, and fuel filters. As of 1995, approximately 1 billion pounds of these materials are in use worldwide.

Materials R&D Related to National Priorities

Environmental Materials Technologies

Concern for the environment is a guiding force of the USDA R&D programs, which includes many projects aimed at reducing the harmful effects of materials processing and increasing the use of recycled materials. Efforts are under way to improve papermaking and the environmental acceptability of related processes; improve wood processing through research on pulping, the production of new chemicals, and nontraditional wood preservation methods; develop systems and technologies for complete, efficient use of recovered paper, paperboard, wood, and plastic waste; and develop biodegradable, starch-based plastics.

Infrastructure Materials Technologies

Many FS R&D activities are devoted to improving the design and performance of wood-based products, including those used in infrastructure applications. Efforts are under way to develop techniques for predicting the performance of products and structures, improve the economic and energy efficiency of structures, develop high-performance products from recycled fiber, provide the technology for fire-safe use of wood-based products, and improve the design of engineered structures to take advantage of wood's economic and environmental advantages over competing materials.

Interaction with the Private Sector

Because USDA research is conducted for the benefit of consumers, agriculture, various industries, states, and the Nation as a whole, the R&D activities are linked closely with non-Federal users. The FS and ARS have entered into a total of more than 800 Cooperative Research and Development Agreements with industry partners since 1988 in an effort to stimulate discoveries in areas of mutual priority and benefit. The USDA also recently initiated two major programs devoted to funding academic and industrial research.

CSREES supports a variety of extramural R&D activities. Its Agricultural Materials program operates on the premise that the public and private sectors must form R&D partnerships. CSREES also establishes cooperative agreements with industrial partners, offers grants, and arranges many other projects bringing government, industry, and academia together to solve problems and to plan and participate in R&D.

Environmentally Sound Wood Bleaching Process Developed

The USDA is working with major pulp and paper companies to commercialize a new method for bleaching wood pulps that would be less harmful to the environment than are present chlorine-based methods while still holding down capital costs. Chlorine reacts with organic materials, such as the lignin in wood, to form cancer-causing dioxin. The new method, developed by Forest Service researchers, employs a powdered polyoxometalate catalyst, which contains oxygen and various metals, such as vanadium. The powder is mixed with water, and the unbleached material is passed through the mixture. The oxygen bleaches the lignin and other colored contaminants, producing carbon dioxide and water, and the catalyst is reclaimed and regenerated. A consortium has been formed with six companies to commercialize the process, which could help industry meet environmental regulations. Still to be resolved are economic viability and catalyst reclamation issues.

Among these efforts is the National Research Initiative (NRI), a competitive grants program offered primarily to individuals or teams of academic researchers. Since its inception in 1990, the NRI has injected millions of new dollars into research addressing issues of the highest priority in agriculture, forestry, and related sciences. Focus areas include development of new uses for agricultural materials through increased efficiency of raw materials processing and enhanced processing and preservation methods, removal of critical barriers to improved wood utilization and expansion of the scientific knowledge base for new R&D, and processes for converting agricultural biomass into alcohol fuels and industrial hydrocarbons.

CSREES also participates in the Small Business Innovation Research (SBIR) program to promote development of agricultural materials. In FY 1991, a new SBIR topic area, Industrial Applications, was initiated. The objective is to develop new or improved technologies that will lead to increased production of industrial products from agricultural materials. Subtopics include oils and lubricants, natural rubber, fuels, chemicals from starch, and fibers. In the Forest and Related Resources topic area, the focus is on developing new production technologies to increase the use of wood. In the Plant Production and Protection topic area, the emphasis is on developing new products or technologies to increase the use of major crop plants.

USDA provides additional support for private-sector research through the AARC Center, created by the U.S. Congress in 1990 to expedite development and market penetration of industrial (nonfood, nonfeed) products made from agricultural and forestry materials. Roughly a third of the projects involve materials; the objective is to bridge the gap between research results and commercialization. Policy and program direction is provided by a nine-member board of directors (eight of whom are non-Federal) representing processing, financial, producer, and scientific interests.

Any private individual or company may apply for assistance through the AARC Center. Most clients are small firms, with preference given to projects that benefit rural communities and are environmentally friendly. Cost sharing is required; the actual ratio of private to public money is closer to 3:1. Money invested by the AARC Center is repaid under negotiable agreements, with a premium for the risk assumed by the center.

Materials R&D Base Programs

Forest Service

The FS Forest Products and Harvesting Research (FPHR) program provides the scientific information and technology needed to harvest, produce, and use wood products in ways that are efficient, safe, and environmentally beneficial.

USDA's "Spaceboard" Improves Prospects for Paper Recycling

A new type of board made of recycled and molded paper pulp, developed by USDA researchers, promises to improve prospects for paper recycling. The inexpensive, lightweight board already has been used commercially -- to make sets for the Twin Peaks television show. Until now, the capability to recycle wastepaper has been limited by contaminants in the various paper grades and the mixing of these grades in the waste stream. These limitations have restricted the used of recycled magazines and mixed office waste in conventional papermaking processes. The problem was overcome by researchers at USDA's Forest Products Laboratory in Wisconsin, who developed "Spaceboard" a three-dimensional molded pulp material. In the processing of this material, provisions can be made to tolerate high levels of contaminants. The process has been licensed to a small California manufacturer and is being commercialized by several companies.

The research is conducted at six of the eight FS field research stations located throughout the nation; about 60 percent of FPHR research expenditures are concentrated at the Forest Products Laboratory in Wisconsin. This research is conducted to meet the needs of consumers, regulatory agencies, industry, land managers, and other scientists.

Wood is composed of three types of polymers, which form a lightweight but strong composite matrix. This complex matrix comprises the connections among the fibers and is the basis of wood's unique mechanical and physical properties. In recent years, research has concentrated on explaining the relationships among the chemical components, the fibers, and the physical properties. Increased understanding of these properties will enhance prospects for combining these components to meet requirements for specific applications.

Within FPHR, the Wood-In-Use program develops and improves the design and performance of wood-based materials and products consistent with the broad environmental objectives of USDA and the FS. An important objective is to improve papermaking and the environmental acceptability of related processes through development of biological pulping methods, biological or other bleaching methods that do not require harsh chemicals, and economical techniques for recycling paper. The Wood Processing and Processes program involves development of high-performance composite materials from wood, wood fibers, and other materials, and biopulping research for both advanced processing and product development.

The recycling of waste wood and waste paper improves the well-being of the environment and creates jobs while conserving timber resource. Discarded paper and solid wood products account for about 44 percent by weight of the solid municipal wastes generated in the United States. More than 58 million tons of wood fiber is landfilled or incinerated each year. Indeed, the Nation is running out of acceptable landfill sites. Therefore, the FS is promoting recycling of paper and wood wastes through advances in recycling technology.

Recycled wood and fiber from landfills have the potential to be transformed into high-value structural composite products. In addition, composites with different performance characteristics can be made by combining recycled wood, plastics, and other materials. FS research is aimed at developing systems and technologies for complete and efficient use of recovered paper, paperboard, wood, and plastic waste. Specific areas of study are as follows:

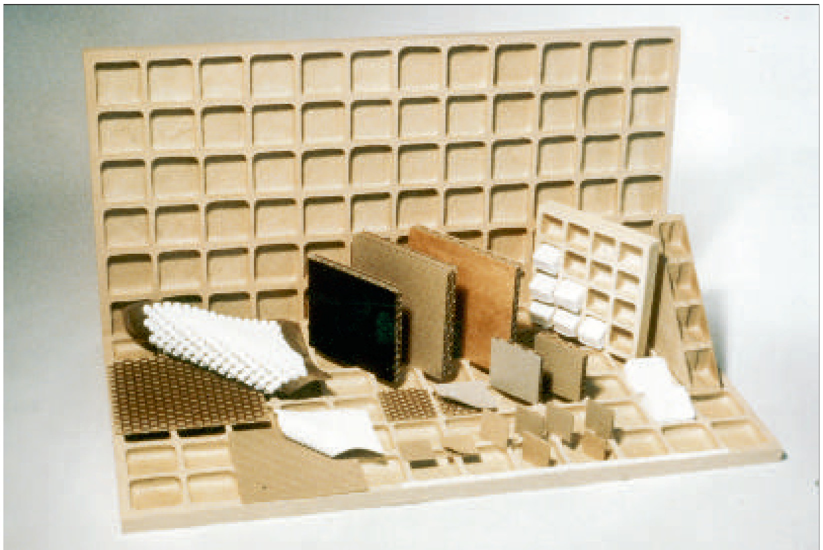
Fiber-reinforced cement products. Wood particles or fibers held together with an inorganic matrix, such as Portland cement or gypsum, can form a composite that could be used in a variety of structural and industrial applications. Research will be conducted to assess and, if necessary, improve the long-term durability, moisture sensitivity, and fire resistance of recycled fiber-reinforced cement products.

Uses for waste wood and plastics. Recycled wood-based fiber and plastics will be used to produce a wide spectrum of products ranging from very inexpensive, low-performance composites to expensive, high-performance building materials. Technology will be developed for converting waste wood and plastics into forms suitable for subsequent extrusion and non-woven web processing. The FS also will study wet-formed structural

Forest Service research has shown that recycled wood-based fiber and plastics can be mixed using nonwoven web processing to form products such as molded interior door frames.

composites, particularly the end-use performance of molded products with respect to fastening, fire resistance, durability, gluing, and finishing; and biological methods for advanced processing and product development.

Use of Recycled Wood in Construction. A major potential market for recycled wood fiber materials exists in the housing and construction industries. Very few of the available wood-based products for these applications consist of materials recovered from post-consumer waste. Great potential exits for providing building products such as siding, interior walls, floor systems, and roof systems made from recycled wood waste and wastepaper.



Forest Service research has demonstrated that recycled wood fiber products can be wet-formed with other materials into a structural web configuration suitable for inexpensive composite building materials.

The FS also is striving to reduce environmental damage resulting from the use of chemicals and high temperatures to convert wood into products. The goal is to modify existing technologies to reduce adverse impacts on the environment while also improving product quality. Research focuses on pulping processes, the production of new chemicals, and the preservation of wood with nontraditional methods.

To carry out bioconversion of wood fibers to new and modified products, researchers must understand how fungi degrade the lignin in wood. Based on this understanding, conversion systems can be explored that reduce wood chips to pulp, make useful chemicals from virgin and waste wood, or upgrade recycled fibers. Successful bioconversion will require sophisticated equipment and processing methods, optimal operating conditions, and detailed evaluation of product properties. Specific areas of study are as follows:

Wood pulping. Wood pulping is more efficient and less polluting when the wood is treated with selected wood-decaying fungi before mechanical pulping. The FS will explore the energy savings and improved paper strength derived from use of superior wood-decaying fungi. The economic viability of biopulping will be explored.

Chemical production. Novel enzymes can be used to treat virgin and recycled wood fibers to maximize sugar yields and concentrations. The resulting sugars can be modified chemically by selected yeasts to produce a variety of chemicals. Sophisticated processing methods and careful examination of the operating parameters will be required to develop a viable process.

Agricultural Research Service

The overall intent of ARS activities is to ensure adequate production of high-quality food and agricultural products to meet the nutritional needs of the American consumer, to sustain a viable food and agricultural economy, and to maintain a quality environment and natural resources base. Materials R&D is carried out in five principal research centers and some smaller units located across the country. The centers develop environmentally safe, value-added industrial and food products and applications based on agricultural commodities and their byproducts; exploit natural biosynthetic systems and associated genes coding for useful products; develop technology in conjunction with USDA action and regulatory agencies and other organizations that will enhance the competitiveness of U.S. agricultural products in world markets; and facilitate and accelerate transfer of technology developed through the centers' R&D programs.

ARS materials and processing R&D involves three classes of commodities: the major bulk commodities produced in the millions of tons, such as corn, wheat, soybeans and cotton; co-products (e.g., cattle hides, rice hulls, casein, butter fat, peanut shells, residues from citrus processing) produced in processing the primary commodities; and newer crops (e.g., kenaf, crotalaria, crambe, lesquerella, meadowfoam), which may yield products not previously obtained from agricultural commodities.

New products are formulated in a variety of ways. The full range of biotechnological methods -- bacterial fermentation, enzymatic transformation, insertion of new genes into existing plants -- is employed to change product characteristics, such as the fatty acid composition in soybean oil. Traditional products also are modified chemically with the tools of synthetic organic chemistry. Other approaches include special mechanical and chemical compounding technology, such as extrusion, encapsulation, and simple blending or mixing of solids or liquids.

Kenaf Plant Finds Many Uses as a Commercial Material

After half a century of USDA research on the use of kenaf in manufactured products, this fast-growing annual crop is finding many new uses in paper, matting, and reinforcing agents. Kenaf grows to a height of 16 feet in 4 to 5 months in the southern United States. The ARS began research in the 1940s on use of kenaf in textiles, such as bags for fertilizer. In the 1970s, the ARS explored use of kenaf as an alternative raw material for paper. In the 1980s, although the private sector, in cooperation with ARS and the Cooperative State Research, Education, and Extension Service, demonstrated the viability of kenaf newsprint, mill financing was unsuccessful due to market conditions. In the 1990s private entrepreneurs began to use the long-fibered "bast" fraction of the plant in high-quality papers. Unbleached bond paper now is manufactured commercially. Kenaf also has replaced wood fiber as a reinforcing agent in thermoplastic and thermoset resin products, such as molded automobile parts. Meanwhile, the short-fibered core fraction of the kenaf plant, which adsorbs six to ten times its weight in oil or water, is being used in oil-spill clean up and other adsorbent applications.

Following are examples of current R&D programs:

Chemicals from New Crops. Industrial chemicals and advanced products can be made from renewable, unique seed oils derived from crops such as cuphea and meadowfoam (which produce oils for specialty applications), lesquerella (hydroxy acid), crambe and rapeseed (erucic acid), vernonia (epoxy acid), and jojoba (wax esters). The resulting products include lubricants, adhesives, waxes, coatings, functional fluids, nylons, greases, soaps, detergents, surfactants, and plastic additives.

Starch-based biodegradable plastics. Advanced extrusion technology permits the conversion of starch into a thermoplastic polymer, which can be shaped into films, sheets, and rods, or

The products shown are based on starch as the principal component. The automotive filter contains super-absorbent material developed by USDA researchers.

possibly injection-molded into articles of various shapes. Co-extrusion of starch with other polymers and/or other additives, both synthetic and natural, produces composite materials with a wide range of properties. One goal is to develop biodegradable, starch-based plastic compositions with suitable properties to replace much of the 60 billion pounds of petroleum-based plastics now produced annually in the United States.

Cotton-based Fabrics with New and Improved Properties. New chemical technology makes it possible to improve the cotton fiber for textile applications. For example, fiber has been developed that improves the comfort of athletic wear by responding to temperature, so that heat is absorbed at high and released at low temperatures. Other advanced fiber properties, such as resistance to abrasion and wear, can be beneficial in home furnishing applications, such as carpeting. In a related program, new technologies are being developed to combine the aesthetic and comfort properties of cotton with the strength properties of the toughest synthetic fibers in a new composite material.

Starch and Other Polysacharides as Encapsulating Agents. Special techniques are being developed to blend and coat pesticides, herbicides, and other agricultural chemicals in such a way as to slow their release after application to crops. The principal process involved is extrusion; chemical mixing with certain polysacharides is also possible. Applications for this technology beyond agricultural chemicals are being sought.

Other ARS research addresses the use of enzymatic, microbial, and chemical conversion systems to convert soybean oil to a variety of materials for use as additives to lubricants and plastics, and as surface coatings, inks for the printing industry, and fuels; conversion of triglycerides from animal fats into specialty materials useful as additives in plastics and lubricants; conversion of natural polysacharides (e.g., pectins, xanthans, livens) into edible films for the coating of fruits, vegetables, and processed foods; and use of agricultural residues (e.g., rice hulls, peanut shells) to absorb heavy-metal ions, such as zinc and copper, from waste streams.

Cooperative State Research Education and Extension Service

CSREES participates in a nationwide agricultural research planning and coordination system known as the State-Federal Partnership, which includes state universities and the agricultural industry. The partnership balances the needs of states, regions, and the nation as part of the land grant university system, which includes an agricultural experiment station in each state. In recent decades, the theme of CSREES activities has been productivity and progress in food and fiber production and distribution worldwide, accomplished through public investment in partnership with the private sector.

CSREES strengthens and advances materials R&D through development and commercialization of nonfeed, nonfood crops and products. Three programs contribute to this effort: Agricultural Materials, the State Agricultural Experiment Stations, and the NRI (described earlier).

Agricultural Materials

The original goal of the Agricultural Materials program was to establish a domestic natural rubber industry based on the guayule shrub, a perennial native to the desert Southwest. The role of this program expanded with passage of the Critical Agricultural Materials Act of 1984, which called for development and

This thermal underwear has a finish (dubbed Polytherm) that absorbs heat with rising temperatures and releases heat at low temperatures.

commercialization of vegetable oils, nonwood fibers, pharmaceuticals, and other agricultural plant materials.

CSREES operates on the premise that the public and private sectors must pool their ideas, people, and resources. Such partnerships help move new nonfood, nonfeed products and processes to a precommercial state -- much closer to the marketplace than in the past -- by systematically identifying and removing barriers to commercialization. Since the mid-1980s, CSREES has established a track record for cooperative agreements with and grants to industrial partners to bring down precommercial barriers through third-party testing, full-scale technology demonstration, or evaluations of development potential. Many other projects bring government, industry, and academia together to solve problems and to plan and participate in projects.

Major projects include the following:

Natural rubber from guayule. Natural rubber and resins are derived from guayule to make products such as aircraft and vehicle tires, coatings, paints, and bioactive organic compounds. Partners include other Federal agencies, universities in five states, and tire companies.

Products from crambe and industrial rapeseed. Oil high in erucic acid and derivatives from crambe and industrial rapeseed is being developed for automatic transmission fluids and supplements, cutting oil, coatings, and, after intermediate conversion to brassylic acid, for nylon 1313. Eight universities, a state board of agriculture, and several small private firms are involved.

Fluids from lesquerella and castor oils. These hydroxy fatty acid oils can impart unique performance properties in functional fluids and greases. Current work focuses on lesquerella, which in chemical structure is two carbon atoms longer than castor oil. Partners include a private research firm, a growers association, a university, and ARS.

Advanced materials from renewable resources. A cooperative program has been launched by USDA and the Department of Defense (DOD) to develop industrial products from renewable, domestically grown materials that have both defense and commercial applications. Materials of interest include biodiesel fuel, engineering nylons, functional fluids, oil absorbents, flexible paints and coatings, epoxides, and natural biocides. Universities, Federal laboratories, and private companies participate. In another joint effort with DOD, starch polymers have been developed for use in various products (e.g., packing materials) that biodegrade in the marine environment. Partners include several universities, small and large private companies, and the National 4-H Council.

State Agricultural Experiment Stations

State experiment stations employ both Federal and state workers, who carry out agricultural research and assist local farmers. Traditionally, the research objective has been to improve the efficiency and effectiveness of agricultural production. A broad range of research has been required, with topics ranging from crop breeding and animal health to conservation practices and economic evaluations. Until recent years, research on conversion of agriculture materials to useful products has been a minor part of the total effort.

Now, experiment stations in many states are engaging in such research. A North Dakota program is making significant advances in converting seed oil from crops such as crambe and rapeseed to brassylic acid for nylons, paints, and coatings. A university-based program in Indiana has played a major role in increasing the efficiency of corn starch conversion to alcohol fuels. Other experiment stations developing joint programs for new industrial uses are located in Nebraska, Missouri, Iowa, Mississippi, and Arizona.

Economic Research Service

The ERS Office of Energy and New Uses (OENU) provides leadership, oversight, coordination, and evaluation for most USDA energy-related activities. The OENU analyzes existing and proposed energy policies, strategies, and regulations concerning or potentially affecting agriculture or rural America and the feasibility of new uses for agricultural products.

This office contributed significantly to the Administration's effort to include renewables in the reformulated gasoline program. The OENU analyzed the positive economic and environmental benefits that would result from the requirement for renewable oxygenates. The OENU will continue to analyze this important market, participate in development and implementation of Clean Air Act regulations affecting ethanol and other biofuels, and evaluate legislative proposals for the USDA that would affect the market.

As the USDA representative on diesel regulatory matters, the OENU is coordinating analyses of the effect of on/off-road engine emissions regulations. The potential for use of biodiesel to help meet new clean air standards for diesel emissions is being investigated. Expanded biodiesel use could foster development of new markets for oilseed producers. The OENU established a USDA Biodiesel Committee to coordinate research and explore biodiesel use. The office also is working with the Department of Energy (DOE) on a congressionally mandated assessment of the agricultural and rural area implications of expanded biodiesel use.

The OENU is working with DOE and the Environmental Protection Agency (EPA) on technical and economic analysis of biomass liquid fuel and electricity. The focus is on technologies that convert plant cellulose and hemicellulose into ethanol. Electricity can be produced by direct combustion of biomass or by gasification technologies using advanced turbine technology. Either process can make use of material from agricultural residues or wastes, or energy crops. If technology development and efforts to improve feedstock yield are successful, then biomass could provide farmers with new market opportunities and rural America with a new industrial base.

Finally, OENU is working with USDA agencies as well as outside groups to advance research activities that promote new uses. Economic analyses are conducted and methods developed to evaluate the effects of new industries on rural economics. In addition, methods for assessing new technologies are being developed to provide USDA scientists and engineers with an ongoing evaluation of new uses research, so that research priorities can be set to maximize economic benefits.

Major Laboratories and Centers of Excellence

USDA has many major research centers or laboratories across the Nation focusing on particular areas of research in technology or forestry and nonfood agricultural materials. These laboratories are staffed by diverse scientists and engineers, who collaborate with public and private sector researchers and maintain constant interchange with scientists from other countries.

The FS Forest Products Laboratory has helped extend the world's timber supply through increased wood use efficiency and product longevity, and through creative product development. The laboratory is a world leader in all aspects of fundamental research in wood-based materials, greatly expanding understanding of wood chemistry, biochemistry, physics, properties, and engineering with the aim of developing improved wood and paper products using environmentally sound processing methods.

The ARS carries on materials research at four major research centers. The mission of these centers is to seek technology that will enable broader utilization of agricultural commodities in food and nonfood uses. A major part of this mission involves the study of materials processing, properties, and performance. All these activities involve contact or close collaboration with industry.

The National Center for Agricultural Utilization Research in Illinois is the largest of the USDA's centers. Its research agenda includes investigations of cornstarch technologies that have applications as biodegradable industrial materials as replacements for environment-damaging materials like petrochemical-based plastics. Improved processing is sought through the development of more efficient batch reactors, extruders, injection and compression molding and thermal treatment coating and laminating systems. Tools of polymer rheology are used to characterize the properties of degradable composites made from starch and oils. Associated research covers fermentation technologies and supercritical fluid processing of soybean and other vegetable oils for products replacing petroleum-based printing inks and fossil-derived diesel fuels.

The Eastern Regional Research Center, in Pennsylvania, carries out the only U.S. research program on cattle hides and leather. One major thrust is the solution of environmental problems in processing, and the other is improvement in basic properties of leather for a variety of enduses. Separate research focuses on films and gums based on carbohydrate raw materials.

The major materials focus at the Southern Regional Research Center, in Louisiana, is cotton and cotton-blend textiles. New yarn and fabric structures, improved resilience (for permanent press), and new textile properties (such as the ability to adjust to heat and cold) are sought. Basic structure studies of cotton fibers, property measurement, and biological study of fiber growth are carried out, with the long-range objective of improving the important fiber properties. Other material studies are concerned with modifying properties of selected oil and protein raw materials.

The Western Regional Research Center, in California, conducts limited materials research on edible films and coatings for fruit and vegetables, and the use of wheat starch in rigid structural materials such as wall board and low density cement.

Material studies also are carried out at some of the 106 other ARS locations. At Clemson University, the Cotton Quality Research unit has developed and is improving the most advanced practical system for measuring and grading the properties of cotton fiber. At the Russell Center, in Georgia, the tools of new infrared reflectance are used in characterization of forages and other materials.

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Annual Reports are available by contacting:

Report Title: Dividends from Wood Research

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Report Title: Agriculture Inventions Catalog

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In addition, the ERS Commercial Agriculture Division publishes the biannual Industrial Uses of Agricultural Materials Situation and Outlook.

National User Facilities

Cutting-edge materials research that pushes the frontiers of knowledge requires the latest equipment and instruments, which sometimes are available only at Federal laboratories. Of particular importance in this regard are the National User Facilities. These unique laboratories, located across the United States, are open to qualified industrial, academic, and foreign researchers for state-of-the-art research. National User Facilities must meet strict criteria with respect to shared funding and quality of work, which is certified by peer-reviewed project selection. These facilities are used by thousands of leading scientists and engineers in many fields, including materials science, chemistry, biology, life sciences, and geology.

The available instruments, many of which are rare or unique in the United States and even the world, are usually too expensive for any one company or university to build, buy, or operate safely. These tools enable the study and development of advanced materials because they satisfy the need to work at atomic and molecular scales with great precision. Users can characterize all types of materials using beams of light, neutrons, or electrons, as well as high magnetic fields. They also can prepare research quantities of non-commercial materials.

Other nations have recognized the importance of facilities like these. The Japanese and the Europeans are building light sources equivalent to those operated by the U.S. Government, and Japan has upgraded its research reactor to provide a cold neutron source. Thus, continued U.S. leadership in materials research depends on enduring support for, and appropriate upgrades of, the National User Facilities.

Three Federal agencies operate the facilities. Following is a summary of the available equipment, usage rates, and types of research carried out.

Neutron Sources

The DOC's National Institute of Standards and Technology (NIST) has developed a capability for research and measurement using neutron sources that is unique in the United States as well as far less expensive than similar facilities being duplicated overseas. A 20-megawatt research reactor (NBSR), in routine operation since 1969, offers a wide range of research instruments, including the $26-million Cold Neutron Research Facility (CNRF), which began operating in 1991 and is expected to be fully operational soon.

The 21,000-square-foot NBSR experimental hall has an experiment-staging area, an eight-beam network of cold neutron guide tubes (a total of 350 meters of guides), and 15 experimental stations proving cold neutron research capabilities. One-third of the experimental stations are developed and maintained by organizations other than NIST. Activities include neutron scattering and diffraction, neutron radiography, chemical trace analysis by neutron activation and depth profiling, fundamental neutron physics, long-term irradiations, and isotope production.

The CNRF accommodates research in materials structure, materials dynamics, chemical analysis, and neutron physics. Two-thirds of the experimental time is available to private-sector researchers, who are scheduled by a panel of experts based on scientific merit. In FY 1993, more than 880 non-NIST researchers, including approximately 130 from industry, used the NBSR/CNRF, a fourfold increase since FY 1987.

Neutrons provide a unique type of radiation because they are neutral and therefore can penetrate bulk solids. (Charged particles, by contrast, are absorbed by or interact with surfaces.) When a neutron beam bombards a target material, the neutrons penetrate the target and then "scatter" in a distinctive pattern, which provides a three-dimensional "picture" of the positions and motions of individual atoms as well as other features, such as magnetic structure. Neutron beams are suited particularly to the study of materials because they can distinguish

The Cold Neutron Research Facility (CNRF) Guide Hall, adjoining the NIST reactor, offers advanced measurement technologies relevant to the materials, communications, transportation, chemical, electronics, and biotechnology industries. Guide tubes transport intense beams of neutrons from a cold source inside the reactor core up to 100 meters to experimental stations in the guide hall. The long wavelength of cold neutrons permits study of large-scale structures, such as polymers, biological molecules, and colloids, while facilitating the study of optical effects, including interference, refraction and nuclear properties. Eleven of the 15 experimental instruments are operational, with the final four under construction. Several of the instrument stations are shown, including 30-meter small-angle neutron scattering (SANS), right foreground; an 8-meter SANS, middle left in orange; and the multidetector time-of-flight spectrometer, lower left.

among the various elements in the periodic table -- something that X-rays, for example, cannot do.

The wavelength of a neutron beam depends on the temperature, which affects the nature of the research. The NBSR provides hot neutrons, which are absorbed quickly, so research instruments must be placed right next to the reactor core. The CNRF cools the neutrons with a block of frozen hydrogen so they can be piped hundreds of feet away from the reactor. This feature not only provides researchers will added space but also reduces unwanted background radiation, thereby improving the signal-to-noise ratio of the data.

Research topics are related to both national goals and commercial interests. For example, in one joint effort involving NIST and a major manufacturer, neutron scattering techniques are being used to investigate the bonding state and molecular dynamics of hydrofluorocarbon 134a, an environmentally safe refrigerant, as part of the effort to improve separation and storage of these advanced materials. Another project involving academic researchers and two Federal agencies employs quasielastic neutron scattering to monitor the motion of water in cement pastes, as part of an effort to understand the freezing process and improve the durability of Portland cement concrete.

Light Sources

NIST also operates beamlines at the National Synchrotron Light Source run by the Department of Energy. The NIST beamlines are used for real-time microstructural characterization of materials. The spectral range and small size of the radiation sources, combined with high-resolution X-ray optics and dedicated instrumentation, make possible a wide variety of measurements in X-ray topography, small-angle scattering, diffraction imaging, high-resolution microradiography, and surface and interface science. Applications include structure determination in disordered materials and ultra-thin films, nondestructive evaluation of imperfections and strains in materials, microstructural characterization of complex crystals, and ultra-sensitive detection of trace elements.

Department of Energy

National User Facilities supported by DOE's offices of Basic Energy Sciences (BES) and Energy Efficiency and Renewable Energy (EE) are built and operated at DOE laboratories. Operating time is available without charge to researchers who publish their results in the open literature; proprietary or non-publishable research is accommodated on a full cost recovery basis. The facilities are not available for research that could be carried out using commercially available facilities or services.

In FY 1994, a total of 4,815 researchers used DOE's National User Facilities and collaborative research centers. Usage is only one measure employed to evaluate these facilities. Other measures include originality, creativity, and uniqueness of opportunities made possible with these facilities; innovation associated with the results; and the quality of the service to users.

Light Sources

Synchrotron light sources produce a spectrum that can be "tuned" to the desired wavelength, a major advantage over the previous generation of X-ray equipment, which had set wavelengths. Furthermore, the development of third-generation synchrotron light sources has produced nearly a 12-order-of-magnitude increase in brightness (defined by the numbers of photons of a given wavelength that can be directed at a small area of a sample). Early synchrotron light sources made use of photons created as the undesirable by-products of electron accelerators built for physics research. Research conducted with these accelerators showed such high promise that later accelerators were built expressly to optimize production of synchrotron radiation for materials science and related experiments.

In an X-ray diffraction experiment, the photons produced by a synchrotron light source interact with the electrons of the atoms in the target material, and the photons are scattered or re-radiated in specific directions. The result is a pattern of spots, which is used to determine the crystalline structure of the target material. Synchrotron radiation often is used to study the near-neighbor and long-range arrangement of atoms in solids.

Today, synchrotron light sources are used for state-of-the-art structural studies of metals, alloys, ceramics, polymers, and biological molecules. BES operates four major synchrotron light sources, each with unique characteristics. The facilities provide X-rays and ultraviolet (UV), visible, and infrared light. Each type of light has a particular wavelength or energy (frequency), which can be used to study structures of a corresponding size. For example, UV radiation (10 to 100 electron-volts) is useful for spectroscopic studies of small molecules, surfaces, and microstructures. Hard X-rays (2,000 to 100,000 electron-volts) are useful for studies of interatomic distances in solids. Soft x-rays (100-2,000 electron-volts) with longer wavelengths are useful for study of larger objects, such as proteins and polymers.

In an example of the type of R&D enabled by light sources, BES recently pioneered development of a technique for detailed study of coordination and bonding in solids on a very short time scale. The Extended X-ray Atomic Fine Structure (EXAFS) technique allows measurements to be carried out in a few seconds, enabling observation of material transformations in near-real time as well as X-ray diffraction identification of crystal structures in real time. Complete diffraction patterns have been collected in times as short as 50 milliseconds. The EXAFS technique is being used to characterize the rapid structural changes associated with industrial welding, to develop a previously unobtainable understanding of the evolution of weld microstructures and properties. This technology also has permitted in-situ examination of inanimate structures of engineering importance and living biological structures, such as bone.

The National Synchrotron Light Source, at Brookhaven National Laboratory, provides the world's most-used source of X-rays and UV radiation for research. A wide range of techniques is used by chemists, solid-state physicists, metallurgists, engineers, and biologists for basic and applied studies. This is a forefront, dedicated facility used for vacuum UV and X-ray spectroscopy and X-ray scattering. The facility serves more than 2,500 users per year.

The Stanford Synchrotron Radiation Laboratory, in California, provides hard X-rays with high energy and short wavelengths, ideal for structural studies. This facility has pioneered many innovations in the generation and use of X-rays. It became independent of the high-energy physics electron injector in 1993. When fully utilized the facility serves about 66 scientists simultaneously. With some new beamlines being commissioned, especially for structural biology, increased scientific activity is expected.

The Advanced Light Source (ALS), at Lawrence Berkeley Laboratory, provides the world's brightest beams of soft X-rays and extreme UV radiation -- photon energy levels ranging from 10 electron-volts to several thousand. This capability is ideal for research on atomic and molecular structure, corrosion, surface phenomena, chemical dynamics, imaging of biological structures, X-ray lithography, and catalysis. The ALS was opened to users in late FY 1993.

The Advanced Photon Source (APS), under construction at Argonne National Laboratory, will be the nation's most brilliant source of X-rays in the energy range from 1,000 to more

Advanced Photon Source - Argonne National Laboratory

than 100,000 electron-volts -- the portion of the spectrum ranging from soft to hard X-rays. The APS will enable studies of material structure in greater detail than ever before, in exposure times of billionths of a second, enabling scientists to make "movies" of catalytic and exzyme reactions. The APS will begin operations in late FY 1996. It will accommodate up to 300 users at once.

Neutron Sources

BES operates four neutron sources. Neutrons are especially useful in research related to DOE's mission because they are sensitive to the presence of lightweight atoms, such as the hydrogen found in many important hydrocarbon molecules (present in common

DOE-Sponsored Research Leads to 1994 Nobel Prize in Physics

The 1994 Nobel Prize in Physics was awarded to retired DOE scientist Clifford G. Shull and Canadian researcher Bertram N. Brockhouse for their pioneering development of neutron scattering as a tool for structural analysis. Their DOE-supported research has had a profound influence on the application of neutron scattering to diverse subjects, such as materials containing hydrogen, magnetic materials, polymers and plastics, superconductors, pharmaceuticals, biological materials, complex fluids, and characterization of residual stress. The fundamental research that led to the award was carried out while Shull was employed at DOE's Oak Ridge National Laboratory from 1946 to 1955. The work was funded by the predecessor to DOE's Basic Energy Sciences/Materials Sciences program, which supported Shull not only at Oak Ridge buy also later at Massachusetts Institute of Technology, until his retirement in 1987.

energy sources) or oxygen, which is crucial to the behavior of high-temperature superconductors. In addition, neutrons are useful in studies of nuclear physics, radiation effects, and the physical properties of materials (e.g., magnetic properties) as well as for making radioactive elements for research and industrial uses.

The High Flux Beam Reactor (HFBR), at Brookhaven National Laboratory, is the Nation's leading facility for neutron-based research in solid-state physics, chemistry, and structural biology. This 27-year-old research reactor has an operating liquid-hydrogen moderator supporting a major program of subthermal neutron investigations. Subthermal neutrons have low energies and can be used to determine spatial relationships among atoms in large molecules, such as proteins, viruses, and polymers. When fully utilized, the HFBR serves nearly 200 users.

The High Flux Isotope Reactor (HFIR), at Oak Ridge National Laboratory, produces the Nation's most intense continuous beam of neutrons for materials research, nuclear chemistry, and radiation damage research. The HFIR also is the world's leading source of neutron-rich isotopes for research, medical, and industrial uses. The multipurpose reactor can serve about 200 users at once. A companion facility, the Radiochemical Engineering Development Center, was built to recover transuranium elements from irradiated targets used in the reactor.

The Intense Pulsed Neutron Source is a spallation neutron source at Argonne National Laboratory serving the physics, materials, chemical, and life sciences research communities. Materials under study include catalysts used in oil refining, high-temperature superconductors for use in power applications, and biological materials that insulate nerve cells. About 200 users conduct experiments each year.

The Manual Lujan Jr. Neutron Scattering Center at Los Alamos National Laboratory has a high peak neutron flux used for materials and other basic research, as well as for DOE's Office of Defense Programs. Studies of the atomic and molecular structures of materials can be performed here quickly, with great accuracy, using small samples. The neutrons are produced through spallation, which involves firing protons at a tungsten target, causing neutrons to be ejected from tungsten nuclei. The neutrons hit the material being examined and are scattered; the scattering pattern provides information about the material's structure. Materials under study include titanium-aluminum alloys (useful for aircraft engines) and dinosaur bones.

Other DOE Materials Facilities

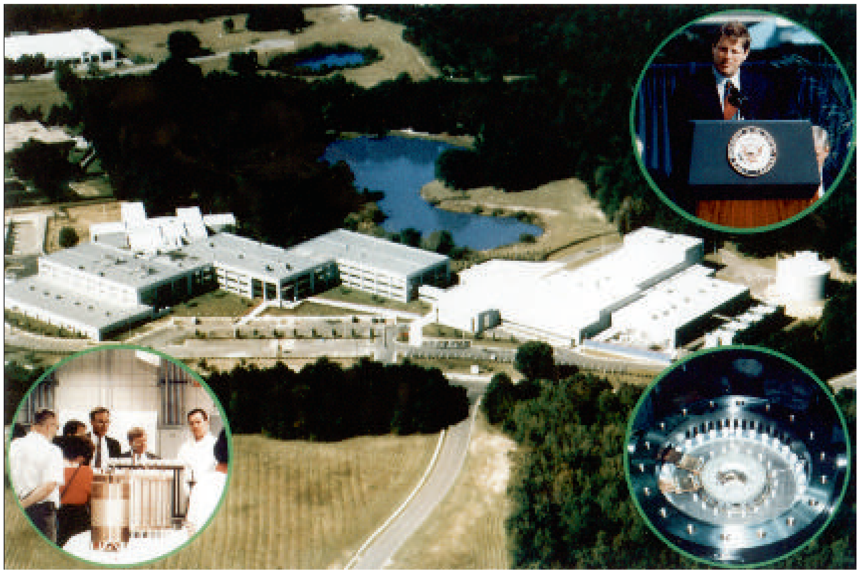
The Materials Preparation Center at the Ames Laboratory at Iowa State University offers centralized one-of-a-kind services and facilities for the synthesis and processing of advanced materials not otherwise available to industry, academia, and government laboratories. It is operated by BES.

Four unusual national user centers for electron beam microcharacterization are located at Argonne National Laboratory, the University of Illinois, Lawrence Berkeley Laboratory, and Oak Ridge National Laboratory. Collectively, they include instruments for high resolution microscopic imaging, micro-electron diffraction, microchemical analysis, and high-voltage in-situ characterizations. They collectively accumulated 892 users in FY 1994. They are operated by BES.

The High Temperature Materials Laboratory (HTML) at Oak Ridge National Laboratory is a state-of-the-art research facility consisting of six user centers equipped primarily for characterizing materials. The centers focus on materials analysis, mechanical properties, X-ray diffraction, physical properties, machining and inspection, and residual stress. The HTML Residual Stress user center is operated in partnership with BES at the HFIR. Additional dedicated facilities are maintained at HTML for the Ceramic Manufacturability center through a partnership with DOE Defense Programs. This center operates instrumentation for conducting sophisticated research on precision machining of advanced ceramic materials, with the goal of working directly with industrial teams to achieve cost effective manufacturing.

National Science Foundation

The NSF's National User Facilities are supported by the Division of Materials Research and are suited particularly for materials research, although they also are used by scientists and engineers in other disciplines. These facilities offer unique experimental capabilities, including



The National High Magnetic Field Laboratory, located in Tallahassee, is operated by Florida State University, the University of Florida, and DOE's Los Alamos National Laboratory. Insets: (upper right) Vice President Gore dedicating the laboratory on October 1, 1994; (lower right) top view of the 30 Tesla (approximately 600,000 times the Earth's magnetic field) resistive magnet, the highest-field resistive magnet ever built; and (lower left) public tour of the new laboratory.

resources for research using high magnetic fields, and they play an important role in the training of future scientists and engineers.

Described here are NSF-supported facilities that are open to all qualified users from universities, industry, and government laboratories.

High Magnetic Fields

The new National High Magnetic Field Laboratory (NHMFL) supports materials research using high magnetic fields and advances magnet and magnet materials technology. The facility is supported by NSF and the State of Florida and operated by the University of Florida, Florida State University (FSU) and DOE's Los Alamos National Laboratory. This new laboratory was developed through a cooperative effort between NSF and the State of Florida.

Research using high magnetic fields plays a key role in the advancement of knowledge about the physical, chemical, biological, and engineering properties of materials. The contributions of high magnetic field research to the current understanding of semiconductors and superconductors, and the impact of nuclear magnetic resonance (NMR) spectroscopy on condensed matter physics, chemistry, biology, and materials science and engineering are testimony to the importance of this branch of research.

NHMFL has available or is developing a number of advanced high-field magnets, including resistive magnets providing continuous fields up to 30 Tesla (T), a 45 T hybrid magnet, state-of-the-art superconducting magnets for high resolution NMR at frequencies up to approximately 1 gigahertz, and pulsed-field magnets providing quasi-continuous fields up to 60 T. A 100 T quasi-continuous pulsed-field magnet system has been proposed.

In addition, NHMFL offers a range of instruments for experiments using these fields. All the magnets are located at FSU, except for the pulsed-field magnets which are located at Los Alamos. An in-house research and educational program involves faculty, post-doctoral staff, and students from several disciplines including physics, chemistry, materials science, engineering and biology.

Light Sources

The Cornell High Energy Synchrotron Source provides hard X-rays for a wide range of materials research, including detailed studies of atomic structures, defects, surfaces, and interfaces of crystalline and amorphous materials, including biological materials.

The Wisconsin Synchrotron Radiation Center provides soft X-rays and UV light for a variety of experiments, including photoelectron spectroscopies of surfaces, measurements of the electronic structure of materials, and fabrication of submicron structures through X-ray lithography.

Neutron Sources

NSF provides support for two beamlines at NIST's Cold Neutron Research Facility for a wide variety of investigations. One beamline is for small-angle neutron scattering employed in studies of alloys, ceramics, composites, polymers, and polymer blends. A second beamline, for spin-polarized inelastic neutron scattering, is used in studies of magnetic materials.

Other NSF Materials Facilities

The National Nanofabrication Users Network (NNUN) is a network of user facilities integrated electronically over the "information superhighway" that offers scientists and engineers access to state-of-the-art fabrication equipment and expertise for the study of novel nanoscale materials and devices. The initial nodes are located at Cornell University and Stanford University, with subsidiary connecting sites at Howard University, Pennsylvania State University, and the University of California at Santa Barbara. Projects using the NNUN include fabrication of nanoscale materials, such as heterosemiconductors and heteroinsulators, and devices used to explore the frontiers of science, such as quantum transport in nanoscale electrical and biological structures. In addition, the NNUN has been used to study microelectromechanical devices and sensors, electro-optical devices, and the science of materials of nanometric dimensions.

Four supercomputer centers are accessible to all qualified scientists and engineers. Roughly 15 to 20 percent of the users are grantees working in materials science and technology. Projects carried out at these centers address electronic structure computations, simulations of crystal growth, diffusion in amorphous alloys, and localized deformation and modeling of composite materials and interfaces.

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National High Magnetic Field Laboratory (NHMFL)
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6. Appendix

Appendix A

National Science and
Technology Council

Committee on Civilian
Industrial Technology

Materials Technology
Subcommittee

Missions and Membership

The Committee on Civilian Industrial Technology (CCIT), one of nine primary NSTC committees, is responsible for government-wide oversight, coordination, and prioritization of R&D and allied technology programs that promote industrial competitiveness and economic growth. Strong linkage with U.S. industry is a guiding principle of the CCIT and its six subcommittees: Materials Technology (MatTec), Manufacturing, Electronics, Automotive, Commercial Environmental Technology, and Construction and Building. (See CCIT and MatTec membership lists on the following pages).

The MatTec subcommittee provides advocacy for Federal materials R&D programs and develops mechanisms that assist and facilitate interagency program planning and implementation in priority areas of focus as well as in development of new technical agendas. MatTec also is responsible for coordinating interagency technical planning, implementation, and tracking of R&D programs, and for disseminating information about these programs, both within and outside of government.

Nine Federal agencies participate in the work of MatTec. Each agency conducts a materials R&D effort that spans one or more steps of the innovation process, including basic and applied research, technology development, and demonstration.

MatTec's specific functions are to

- assess materials issues relating to National science and technology priorities and develop information and provide recommendations on needed technical programs and focused initiatives;
- coordinate and interact with NSTC committees and subcommittees and provide advocacy for materials issues in all Federal interagency crosscuts and initiatives;
- coordinate interagency technical program planning and implementation and foster and coordinate interaction with the private sector for the development of public-private materials R&D program plans in priority areas;
- collect, maintain, and disseminate up-to-date inventories of Federal materials R&D programs; and
- prepare and publish timely MatTec report(s) on Federal programs in materials science and technology and, as appropriate, selected topical reports.

Committee on Civilian Industrial Technology (CCIT)

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Honorable Mary Good,
Department of Commerce

Vice Chair

Dr. Martha Krebs, Department of Energy

Co-Chair

Honorable Lionel Johns,
Office of Science and Technology Policy

Principal Members and Alternates

Dr. Joseph Bordogna,
National Science Foundation

Mr. Mortimer Downey,
Department of Transportation

Ms. Lisa Gaisford,
Office of Management and Budget

Dr. Floyd Horn, U.S. Department of Agriculture

Dr. Anita Jones, Department of Defense

Mr. Jonathon Low, Department of Labor

Mr. V. Larry Lynn,
Department of Defense (ARPA)

Mr. Al McGartland,
Environmental Protection Agency

Dr. Arati Prabhakar,
Department of Commerce (NIST)

Dr. Robert Whitehead,
National Aeronautics and Space Administration

Subcommittee Chairpersons

Dr. Joseph Bordogna,
National Science Foundation - Manufacturing

Dr. Lance Glasser,
Department of Defense - Electronics/NEMI

Honorable Mary Good,
Department of Commerce - Automotive/PNGV

Dr. Maryanna Henkart,
National Science Foundation -
Biotechnology Research

Dr. Lyle Schwartz,
Department of Commerce -
Materials Technology

Dr. Richard Wright, Department of Commerce -
Construction and Building

Materials Technology Subcommittee (MatTec)
Committee on Civilian Industrial Technology (CCIT)

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Department of Commerce (NIST)

Executive Secretary

Samuel J. Schneider,
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Principal Members and Alternates

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James Eberhardt, Department of Energy

Alfred Galli, Environmental Protection Agency

Robert Gottschall, Department of Energy

William Harris, National Science Foundation

Garrett Hyde, Department of the Interior

Richard Livingston,
Department of Transportation

Thomas Pasko, Department of Transportation

Robert Pearce,
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Jerome Persh, Department of Defense

Bhakta Rath, Department of Defense

Howard Rosen, U.S. Department of Agriculture

Fred Schottman, Department of the Interior

Gerald Seidel,
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Iran Thomas, Department of Energy

Judith Vaitukaitis, National Institutes of Health

John T. Watson, National Institutes of Health

Benjamin Wilcox, Department of Defense (ARPA)

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Robert Leheny, Department of Defense (ARPA) -
Electronics

Steve Moran, National Aeronautics &
Space Administration - Aeronautics

Thomas Pasko, Department of Transportation -
Infrastructure

Lyle Schwartz, Department of Commerce (NIST) -
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Nondestructive Evaluation

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Appendix B
Classes of Materials

These categories include both traditional and advanced materials ("advanced" refers to the most recent evolutionary developments within a materials class or application category).

BIOMATERIALS AND BIOMOLECULAR MATERIALS are diverse materials that are compatible with human tissues and/or mimic biologic phenomena, as well as materials made from products of biological origin. Traditional materials in this category include dental fillings or crowns. Advanced materials are made from metals, ceramics, and polymers; applications range from artificial hearts to ultra-tough ceramic tank armor modeled on the molecular structure of abalone shells, and biodegradable plastics for use in packaging and fast-food containers.

CERAMICS are materials made from nonmetallic inorganic minerals. Ceramics are noted for their light weight, hardness, corrosion resistance, and tolerance to high temperatures. Spark plug insulators are a traditional example. Advanced ceramics are used for thermal coatings, and in structures of high-temperature engines.

COMPOSITES are hybrids of two or more materials, usually reinforced ceramics, metals, or organic-matrix materials. These materials combine the most useful properties of each component. Fiberglass is a traditional composite, composed of glass fibers in an epoxy matrix. Advanced composites have both structural and non-structural applications and often are used in air and land vehicles.

ELECTRONIC MATERIALS are active materials, such as semiconductors, that transmit signals by way of electrons. These materials are processed to form elements in circuitry. Current electronic technology is based on silicon. A newer material is gallium arsenide. This class also includes metals, ceramics, and polymers used in electronic wiring, interconnections, and packaging.

MAGNETIC MATERIALS are metallic, organic, or ceramic-based materials in which electron "spins" are arranged in certain structures, such that the materials either attract or repel each other, depending on their orientation. When magnets are moved relative to a coil of wire, an electrical field is generated. Iron metal is a traditional magnet. The much stronger iron-rare earth alloy magnets are among the advanced varieties.

METALS are ductile, strong structural materials and electrical conductors. Traditional metals include commodity alloys of elements such as iron and aluminum. Advanced metals tailored for specialty applications are predominantly lightweight aluminum alloys and high-temperature/high-strength intermetallics.

OPTICAL/PHOTONIC MATERIALS are materials that transmit light, materials used for light sources, such as lasers, and materials that are used to switch and modulate light. Glass in numerous forms, from window panes to optical fibers, continues to be an important material. Compound semiconductors, such as gallium arsenide, and complex structures made from such materials play an important role in modern communications systems.

POLYMERS are large molecules consisting of long chains of repeated units. Polymers are noted for unique combinations of properties and have a range of applications, from plastic containers to liquid crystal displays. Plastic wrap is a traditional example; polyimides are advanced, high-temperature polymers used for electronic packaging and aircraft skins.

SUPERCONDUCTING MATERIALS are materials that carry electrical currents with no resistance. Some metals and alloys exhibit this characteristic only at temperatures approaching absolute zero. Advanced varieties, including oxides, organics, and some intermetallics, superconduct at higher temperatures.

OTHER/NON-SPECIFIC MATERIALS is a category encompassing a variety of substances and activities not easily classified, such as R&D involving generic test methods and reference materials, anti-corrosion coatings, paints and lubricants, battery materials, insulation materials, phase diagrams, ores and minerals, textile design, quantum fluids, clays, microgravity science, and comparative risk assessments.

Appendix C
Overcoming Barriers to Commercialization

The Federal materials R&D program is designed not only to advance scientific understanding but also to help U.S. industry overcome the many technical obstacles to rapid commercialization of advanced materials. Today, the commercialization process may consume a decade or more -- too long to provide the quick return companies need to compete in today's marketplace. The phases of advanced materials development are summarized here, with the impediments noted in italics.

In its broadest sense, advanced materials development encompasses basic and applied research from the laboratory to pilot-plant scales; the systematic application of this research to the creation and/or improvement of useful materials and processing methods for a given application; and the design, testing, and characterization of all materials and components, from research samples to prototype pieces.

The first phases are acquisition of raw or recycled materials and refining or other initial transformations. While seemingly remote from product commercialization, raw materials and associated refining processes can add substantially to the overall monetary and environmental costs of advanced materials. An example is aluminum, which is produced from mined bauxite; aluminum currently costs far too much to be used to make lightweight materials for highly fuel-efficient automobiles. *If advanced materials are to be commercially useful, then raw materials and the associated acquisition and refining processes must be affordable, the use of recycled and recyclable materials must be maximized, and there must be little or no waste generated. Achievement of these objectives may depend on Federal support, because the U.S. mining and minerals industries (with the exception of synthesized chemicals) are in decline.*

Meanwhile, researchers must gain a fundamental understanding of material types and undertake more specific characterization of particular materials. Measurements are taken to determine material properties, performance (behavior under simulated or actual conditions of use), structure, and composition, and new or improved instruments are developed to obtain chemical and geometric descriptions of materials from the atomic and molecular to the macro scale. NSF specializes in this type of research, addressing all types of materials; one current focus area is biomolecular materials. *Advanced materials are, by definition, so new that understanding of their characteristics is always incomplete. This type of incremental research seldom is tied directly to commercial applications; as such, it is unlikely to be conducted on a broad basis without Federal support.*

The next phase is comprehensive collection, evaluation, and validation of data on materials structure, composition, properties, and performance, and the relationships among these elements. To be most useful, such information must be consolidated into electronic databases. Researchers then must input this data into relational databases that link the properties, performance, and other characteristics of a material to processing parameters. These databases are used in designing new materials. An example is DOC's evolving database on environmentally safe refrigerants. *The development of comprehensive databases on advanced materials is beyond the resources and interest of individual or even groups of companies and therefore requires Federal support. At present, few materials design databases exist, and those few are not standardized.*

In developing complex materials, researchers employ materials theory, modeling, and simulation, computational tools that support quantitative understanding, design, and prediction. For example, parallel-architecture supercomputers at Oak Ridge National Laboratory are being used to optimize welding, superplastic forming, and other processes. Models also are used in DOT's crashworthiness testing of new vehicle designs and materials. *Development of such tools is expensive and requires the expertise of many disciplines; Federal support is therefore essential. Prediction of material life-cycle performance remains an imperfect art, due to the many gaps in fundamental understanding of advanced materials. In addition, new materials design methods are needed; those used for traditional materials tend to be inappropriate.*

Synthesis and processing is a broad phase that includes the fabrication of new or significantly improved materials and the transfer of laboratory achievements to pilot scale and manufacturing plants. Examples include USDA's efforts to improve and commercialize wood-based products, and DOE's support for the development of applications (such as wires) for high-temperature superconducting materials. *The development of cost-effective methods for processing delicately engineered materials, particularly in large volumes, is a major challenge. Federal support is essential, because the high risk of failure or low return deters industry investment. Further, process modeling requires skill and resources that many companies lack. Concurrent engineering, which is essential to both synthesis and processing of low-cost materials, is still not universally employed. Advanced sensors and other technologies are needed for on-line process monitoring and control.*

The synthesis, processing, and testing of advanced materials depend on the availability of standards for nondestructive and destructive test methods and for materials design. Standard reference (calibration) materials also are needed. The availability of standards fosters the rapid application of materials, expands markets, and reduces material certification costs. DOC is promoting efforts in the United States and at the international level to set standards for advanced materials. *At present, such standards and reference materials are often inadequate or lacking, a significant problem in the testing of advanced materials. Industry long has depended on the Federal Government to facilitate the development of standards and reference materials.*

Manufacturing is the final stage of commercialization. Scaling up production of a new material from laboratory quantities to precompetitive and then commercial stages requires reliable testing procedures, extensive materials property data, and appropriate changes in processing and manufacturing technologies. These issues will be addressed, for example, in the Partnership for a New Generation of Vehicles. *Today, many of these requirements must be met through trial and error. Commercial production and use of a new material also may be impeded by inflexible manufacturing practices as well as the narrow markets and inflated costs associated with advanced materials, a relic of their historical basis in the defense and space industries. The Federal Government can assist industry in overcoming these barriers.*

Appendix D
Acronyms

A

AARC . . . . Alternative Agricultural Research and Commercialization Center
AFOSR . . . . Air Force Office of Scientific Research
ALS . . . . Advanced Light Source
AMMT . . . . Aeronautics Materials and Manufacturing Technologies
APS . . . . Advanced Photon Source
APU . . . . Auxiliary Power Unit
AR&TD . . . . Advanced Research and Technology Development
ARL . . . . Army Research Laboratory
ARO . . . . Army Research Office
ARPA . . . . Advanced Research Projects Agency
ARS . . . . Agricultural Research Service
AST . . . . Advanced Subsonics Technology
ATP . . . . Advanced Technology Program

B

BES . . . . Basic Energy Sciences
BFRL . . . . Building and Fire Research Laboratory

C

C&B . . . . Subcommittee on Construction and Building
CAD . . . . Computer-aided Design
CAML . . . . Computing and Applied Mathematics Laboratory
CAV-ATD . . . . Composite Armored Vehicle-Advanced Technology Demonstrator
CCIT . . . . Committee on Civilian Industrial Technology
CENR . . . . Committee on Environmental and Natural Resources
CFCC . . . . Continuous Fiber Ceramic Composite
CHESS . . . . Cornell High Energy Synchrotron Source
CHRNS . . . . Center for High Resolution Neutron Scattering
CIP . . . . Ceramic Insertion Program
CNRF . . . . Cold Neutron Research Facility
COE . . . . Centers of Excellence
CONMAT . . . . High-Performance Construction Materials and Systems Program
CRADA . . . . Cooperative Research and Development Agreement
CSREES . . . . Cooperative State Research, Education, and Extension Service
CSTL . . . . Chemical Science and Technology Laboratory

D

DOC . . . . Department of Commerce
DOD . . . . Department of Defense
DOE . . . . Department of Energy
DOI . . . . Department of the Interior
DOT . . . . Department of Transportation

E

EC . . . . European Community
EE . . . . Office of Energy Efficiency and Renewable Energy
EEEL . . . . Electronics and Electrical Engineering Laboratory
EMWG . . . . Electronic Materials Working Group
EPA . . . . Environmental Protection Agency
ER-LTA . . . . Energy Research-Laboratory Technology Applications
ERC . . . . Engineering Research Center
ERS . . . . Economic Research Service
EXAFS . . . . Extended X-ray Atomic Fine Structure

F

FAA . . . . Federal Aviation Administration
FCDS . . . . Fatigue Crack Detection System
FDA . . . . Food and Drug Administration
FHWA . . . . Federal Highway Administration
FPHR . . . . Forest Products and Harvesting Research
FRA . . . . Federal Railroad Administration
FRP . . . . Fiber-reinforced-plastic
FS . . . . Forest Service
FSU . . . . Florida State University
FTA . . . . Federal Transit Administration

G

GOALI . . . . Grant Opportunities for Academic Liaison with Industry

H

HFBR . . . . High Flux Beam Reactor
HFIR . . . . High Flux Isotope Reactor
HHS . . . . Department of Health and Human Services
HTML . . . . High Temperature Materials Laboratory
HTS . . . . High Temperature Superconductivity

I

IHPTET . . . . Integrated High Performance Turbine Engine Technology
IPM . . . . Intelligent Processing of Materials
ISO . . . . International Organization for Standardization
ISTEA . . . . Intermodal Surface Transportation Efficiency Act

J

JPL . . . . Jet Propulsion Laboratory

L

LBL . . . . Lawrence Berkeley Laboratory
LDEF . . . . Long Duration Exposure Facility

M

MARAD . . . . Maritime Administration
MatTec . . . . Materials Technology Subcommittee
MEP . . . . Manufacturing Extension Partnership

MIT . . . . Massachusetts Institute of Technology
MMC . . . . Metal-matrix composite
MPM . . . . Materials processing and manufacturing
MRCE . . . . Minority Research Center of Excellence
MRG . . . . Materials Research Groups
MRL . . . . Materials Research Laboratories
MRPC . . . . Materials Research Partnerships Center
MRSEC . . . . Materials Research Science and Engineering Center
MRSEC . . . . Materials Research Science and Engineering Centers
MSEL . . . . Materials Science and Engineering Laboratory
MSFC . . . . Marshall Space Flight Center

N

NAS . . . . National Academy of Sciences
NASA . . . . National Aeronautics and Space Administration
NBS . . . . National Biological Service
NBSR . . . . Neutron Research Reactor
NCHRP . . . . National Cooperative Highway Research Program
NCRR . . . . National Center for Research Resources
NDE . . . . Nondestructive Evaluation
NDI . . . . Nondestructive Inspection
NDT . . . . Nondestructive Testing
NEI . . . . National Eye Institute
NEMI . . . . National Electronics Manufacturing Initiative
NHLBI . . . . National Heart, Lung, and Blood Institute
NHMFL . . . . National High Magnetic Field Laboratory
NHTSA . . . . National Highway Traffic Safety Administration
NIAID . . . . National Institute of Allergy and Infectious Diseases
NIAMS . . . . National Institute of Arthritis and Musculoskeletal and Skin Diseases
NICHD . . . . National Institute of Child Health an Human Development
NIDCD . . . . National Institute on Deafness and Other Communication Disorders
NIDDK . . . . National Institute of Diabetes and Digestive and Kidney Diseases
NIDR . . . . National Institute of Dental Research
NIGMS . . . . National Institute of General Medical Sciences
NIH . . . . National Institutes of Health
NII . . . . National Information Infrastructure
NINDS . . . . National Institute of Neurological Disorders and Stroke
NIST . . . . National Institute of Standards and Technology
NMR . . . . Nuclear magnetic resonance
NNUN . . . . National Nanofabrication Users Network
NRI . . . . National Research Initiative
NSF . . . . National Science Foundation
NSTC . . . . National Science and Technology Council

O

OENU . . . . Office of Energy and New Uses
OFE . . . . Office of Fusion Energy
OIT . . . . Office of Industrial Technologies
ONR . . . . Office of Naval Research
ORNL . . . . Oak Ridge National Laboratory
OSTP . . . . Office of Science and Technology Policy
OTM . . . . Office of Transportation Materials
OTT . . . . Office of Transportation Technologies

P

PC . . . . High-performance concrete
PL . . . . Physics Laboratory
PNGV . . . . Partnership for a New Generation of Vehicles

R

R&D . . . . Research and Development
RAINBOW . . . . Reduced and Internally Biased Oxide Wafer
RD&E . . . . Research, development, and engineering
RF . . . . Radio frequency
RSPA . . . . Research and Special Projects Administration
RTCC . . . . Research and Technology Coordinating Committee
RTG . . . . Radioisotope thermoelectric generator
RWR . . . . Radar Warning Receiver

S

SANS . . . . Small-angle neutron scattering
SBIR . . . . Small Business Innovation Research
SBTT . . . . Small Business Technology Transfer
SIA . . . . Semiconductor Industry Association
SRC . . . . Synchrotron Radiation Center
SRM . . . . Standard Reference Material
STC . . . . Science and Technology Center
SURF . . . . Synchrotron Ultraviolet Radiation Facility

T

TJR . . . . Total joint Replacement
TRB . . . . Transportation Research Board
TRIP . . . . Transformation-induced Plasticity
TRP . . . . Technology Reinvestment Program
TS . . . . Technology Services
TUO . . . . Technology Utilization Office

U

URI . . . . University Research Initiative
USBM . . . . U.S. Bureau of Mines
USCAR . . . . U.S. Council for Automotive Research
USCG . . . . U.S. Coast Guard
USGS . . . . U.S. Geological Survey
USDA . . . . U.S. Department of Agriculture
UTCP . . . . University Transportation Centers Program
UV . . . . Ultraviolet

V

VAMAS . . . . Versailles Project on Advanced Materials and Standards

7. Subject Index

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To facilitate rapid distribution, this document can be accessed in full color or black and white through the World Wide Web (WWW) in portable document format (PDF) using an HTML Browser and the Internet Home Page electronic addresses for the following Government organizations:

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