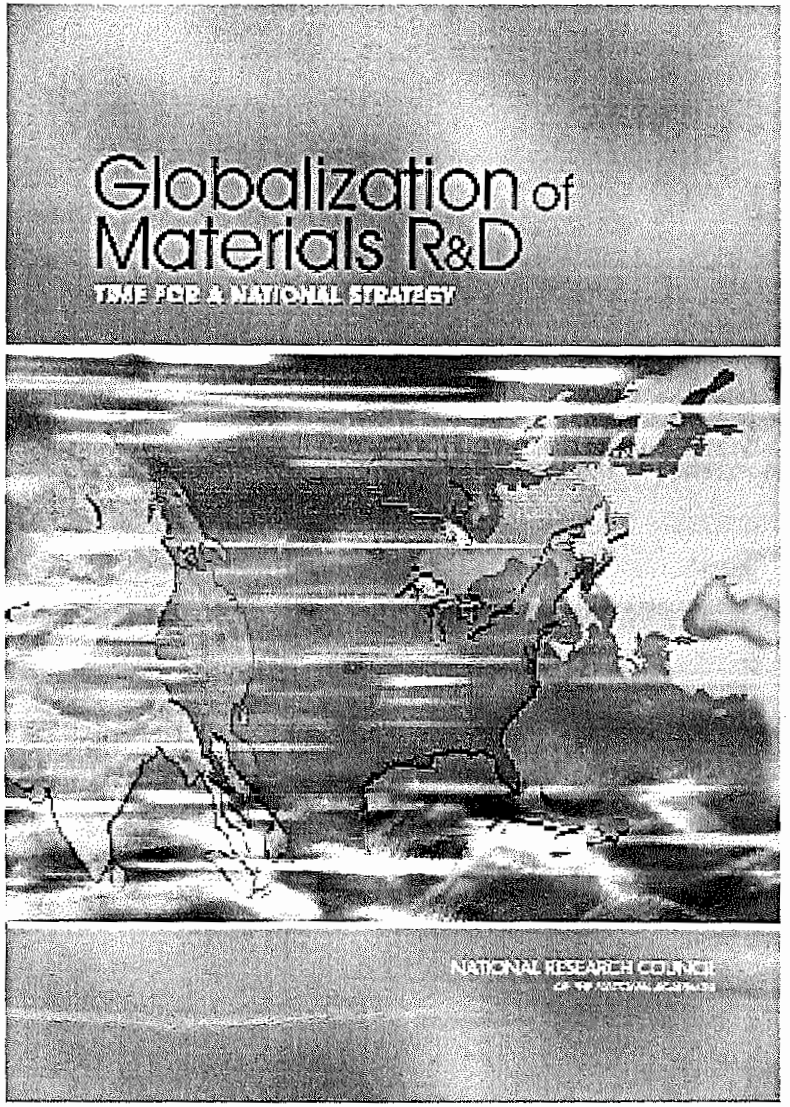
Peter Bridenbaugh, *Chair,* retired in 1998 from Alcoa as an executive vice president responsible for expanding the use of aluminum in automobiles and integrating Alcoa's technical and commercial initiatives in the automotive market. He joined Alcoa in 1968 at Alcoa Laboratories, and after a number of positions was appointed executive vice president and chief technical officer in 1991, at which time he was given overall responsibility for R&D, engineering and environment/safety/health. In 1994, he was given direct responsibility for the automotive market. He led Alcoa Laboratories from 1983 until May 1995. Dr. Bridenbaugh received a bachelor's degree in mechanical engineering, a master's degree in metallurgy from Lehigh University, and a Ph.D. in materials science from the Massachusetts Institute of Technology (MIT).

Dr. Bridenbaugh has served on advisory boards for several universities throughout the United States and two government laboratories. He was a double subject editor—corrosion and nonferrous metals—for the *Encyclopedia of Materials: Science and Technology* and served on the advisory committee for writing the history of Corning, Inc. He has chaired national conferences for the Federation of Materials Societies and the Industrial Research Institute (IRI). Dr. Bridenbaugh also served on several corporate boards, including Precision Castparts Corporation and Keystone Powdered Metal Company. He is a member of the National Academy of Engineering, Sigma Xi, American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME), the American Society for Metals (ASM), the Minerals, Metals and Materials Society (TMS), the Materials Research Society (MRS) and IRI. He has received the following honors: National Materials Advancement Award, Federation of Materials Societies; Hoyt Lecture, American Foundryman's Society; fellow, ASM International; Zae Jeffries Lecture, ASM; Leadership Award, TMS; Alpha Sigma Mu Lecture, ASM-TMS; Andrew Carnegie Lecture, ASM; Distinguished Lecture on Materials and Society, ASM-TMS and ASM Honorary Membership-2004.



Globalization of Materials R&D

Summary Presentation

Summary Presentation

Dr. Peter Bridenbaugh

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

Globalization of Materials R&D

The NRC's ***Committee on Globalization of Materials Research and Development*** was appointed in December 2003 to assess the status and impacts of the globalization of materials science and engineering (MSE) research and development (MSE R&D).

The committee's report was released on August 1, 2005.

The report

- Assesses the current status of materials science and engineering research and development from a global perspective;
- Identifies the drivers of U.S. companies' decisions to locate materials research in the United States or abroad;
- Assesses the impact of the globalization of MSE R&D on the U.S. economy and national security; and
- Recommends actions to ensure continued U.S. access to critical MSE R&D.

This study was carried out under the oversight of the National Materials Advisory Board

COMMITTEE ON GLOBALIZATION OF MATERIALS RESEARCH AND DEVELOPMENT

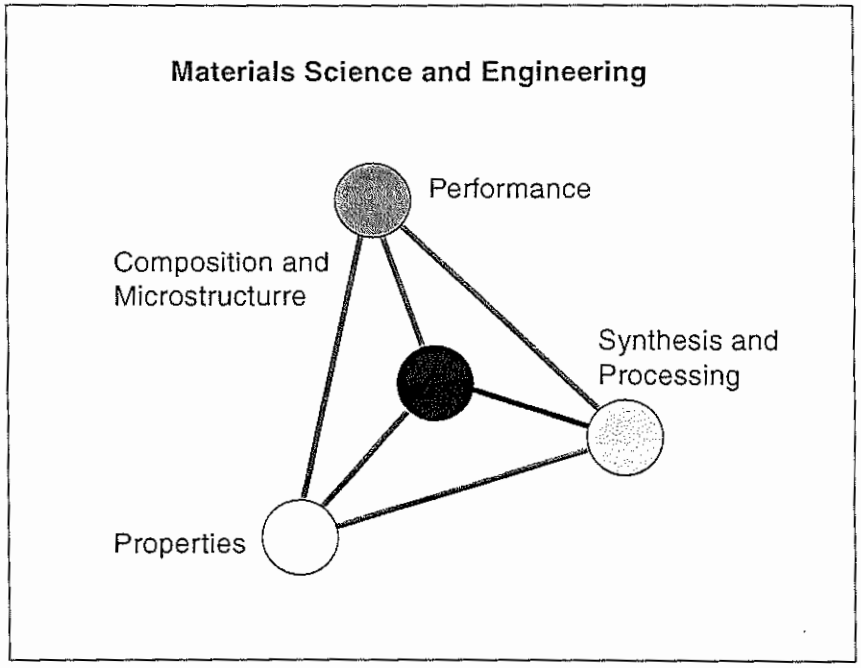
PETER BRIDENBAUGH, *Chair*
MILLER ADAMS, The Boeing Company
ASHISH ARORA, Carnegie Mellon University
GILBERT BENAVIDES, Sandia National Laboratories
UMA CHOWDHRY, DuPont Company
EDWARD DOWLING, DeBeers Group
GORDON GEIGER, University of Arizona
JENNIE HWANG, H-Technologies Group, Inc.
MICHAEL JAFFE, Rutgers University
ROBERT PFAHL, International Electronics Manufacturing Initiative
NATALIA TAMIRISA, International Monetary Fund
XISHAN XIE, University of Science and Technology Beijing

Staff
MICHAEL MOLONEY, Study Director (from Sept. 2004)
TONI MARECHAUX, Study Director (Dec. 2003-Sept. 2004)
MARTA VORNBROCK, Research Associate
LAURA TOTH, Senior Program Assistant

- The committee met four times in person and held several teleconferences over the course of the study.
- In addition, numerous private interviews were conducted with individuals and colleagues in academia, the federal research agencies, and industry.
- The committee also organized a poll of a self-selected sample of members of the materials community.
- The report review process was coordinated by Dr. Elsa Garmire and the committee is grateful to her, the panel of reviewers, and many other colleagues (as mentioned in the report) who made invaluable contributions to the report.

Definition

- Globalization of MSE R&D is defined in this study as the worldwide expansion of MSE knowledge-creation centers as a result of U.S. and non-U.S. industry and government investments along with increased worldwide collaboration facilitated by information technology.



Measuring Trends in the U.S. Position in MSE R&D

- Trends in global R&D activity can be difficult to demonstrate with clarity.
- The committee decided to assess the U.S. position in various MSE subfields using these methodologies:
  - Examining trends in MSE-related patent data;
  - Examining trends in the national origins of MSE literature in major scientific journals;
  - Considering trends in U.S. MSE education and in the activities of professional societies;
  - Conducting a poll of the MSE community; and
  - Revisiting the predictions of a recent NRC benchmarking study as a snapshot benchmarking of MSE today.

Quick Summary of Findings

- Data from the NSF and other sources indicate increases in all fields in transnational academia-led R&D with international academic and industrial collaborators as well as in transnational corporation-led R&D with foreign affiliates of U.S. corporations, foreign academics, or foreign corporations.

- Patent and literature surveys suggest that at the moment the United States remains either the world leader or among the world leaders across the MSE subfields.

- The benchmarking evidence in this report and from a previous study[1] paints a varied picture across the MSE subfields, indicating that the United States leads in some critical areas and is among the leaders in others.

- In some subfields, however, all the data suggest that the probability of the United States maintaining leadership in MSE R&D varies from uncertain to unlikely.

Quick Summary of Findings (contd.)

- Available data show that companies globalize their R&D for a number of reasons, including the availability of expertise, the impacts of regulatory regimes, proximity to new international customers, and cost savings.

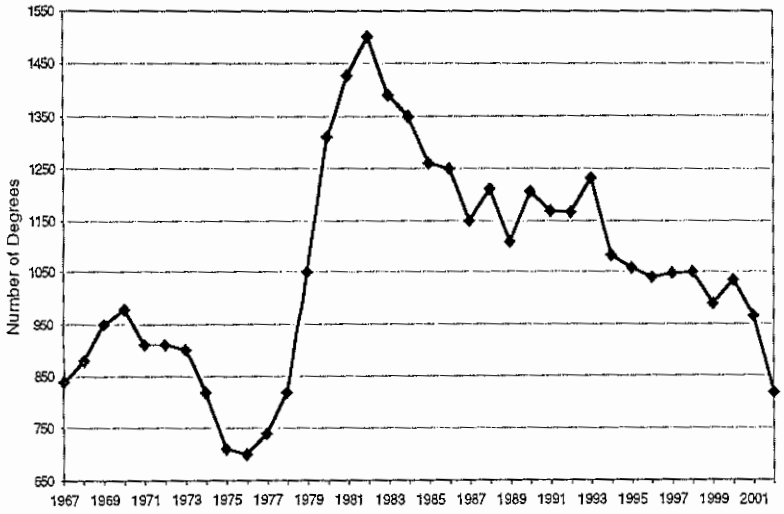
- Risk factors include concern about the ownership of intellectual property and the security of trade secrets, as well as wider concerns about the rule of law and democratic institutions, particularly in developing economies.

- With the emergence of new centers of high-value research across the globe has come a new, market like demand for the world's finest students and experts, challenging the ability of the United States to attract top researchers.

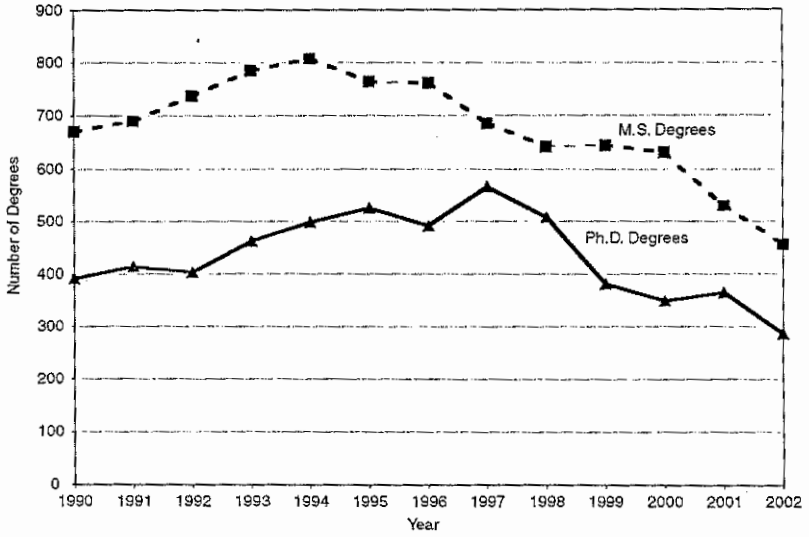
[1]National Academy of Science, National Academy of Engineering, Institute of Medicine, *Experiments in International Benchmarking of U.S. Research Fields*, Committee on Science and Engineering Public Policy, Washington, D.C.: National Academy Press (2000).

Some Trends in MSE Education

Undergraduate degrees awarded in metallurgy and materials engineering since 1967.



Graduate degrees awarded in metallurgy and materials engineering since 1990.



Challenges for the MSE educational system:

- The increasingly broad curricula in materials departments;
- The decreasing attraction of MSE as a career choice for high school and university graduates; and
- The continuing dependence of graduate programs on attracting foreign students in an increasingly competitive global market for the best students.

Quick Summary of Discussion on Impacts

- The impact on the U.S. economy of globalized MSE R&D is likely to differ across materials subfields.
- On the one hand, a decline in domestic MSE R&D in particular subfields might have a negative effect on domestic growth, wages, and jobs in those and other MSE R&D subfields and industries dependent on materials research.
- On the other hand, a relative decline in MSE R&D in one subfield might release resources for investment in another, more promising subfield in which the United States enjoys a comparative advantage, thus enabling U.S. firms to generate new knowledge, products, and growth in the medium term.
- Similarly, relocating overseas any MSE R&D that can be performed more efficiently by foreign counterparts might allow U.S. firms to expand other domestic MSE R&D, thereby increasing the global knowledge base that will stimulate innovation in all countries. One result could be a new comparative advantage for the United States if it can integrate the results of domestic and global research to create new, higher-value products.
- On balance, the United States may well gain from globalization of MSE R&D, provided that conditions in the private and public sectors lead to increased U.S. productivity, efficiency, and capacity for innovation.

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Quick Summary of Discussion on Impacts

- The ability to meet 21st century U.S. defense needs will depend on R&D in materials and processes to improve existing materials and achieve breakthroughs in new materials and combinations. It is clear, therefore, that the evolution of MSE research will impact U.S. capabilities to defend against emerging threats.
- The global shifts in MSE R&D cannot be reversed or stopped.
- Even if the United States were to make great efforts to keep American technologies, knowledge, and capabilities under its control, the investments that other governments are making in their own domestic knowledge-creation capabilities will challenge America's military, homeland defense, and intelligence communities in their attempts to maintain a 1- to 2-generation lead in technology.
- The loss of a national capacity in MSE R&D, and of the manufacturing capability to take advantage of that R&D, is not just a matter of national pride or international image. In a knowledge-based future, only an America that continues to have access to and, in many cases, to generate cutting-edge science and technology will sustain its world leadership in national-security and homeland-defense capabilities.
- It is possible that increased global activity will lead to innovations, discoveries, and technologies that open new global paths for the U.S. to acquire access to the best materials and technologies required for national security and homeland defense. In addition, it is widely accepted that economic growth around the world, and the growth of international trade, can help underpin global security. In this sense, the globalization of research might benefit U.S. national security.
- However, the benefits are not certain and neither are the risks.

Some Thoughts

- The present study concludes that the globalization of MSE R&D is under way and is affecting U.S. leadership across MSE subfields.
- The impact of materials R&D globalization can be positive and large, but the risks of a negative impact remain substantial.
- To avoid a negative impact, the U.S. government and private sector must exploit foreign or joint R&D to benefit domestic innovation by integrating it efficiently and effectively into domestic civilian and military R&D.
- In this context, the question that arises is how the United States can maintain access to the global output of MSE R&D and thereby maintain a leadership position.
- There are risks, including that some knowledge generated by foreign R&D will not be absorbed in the United States and that there may not be sufficient domestic U.S. expertise to recognize the foreign innovation and maximize its integration.
- Maintaining access to current MSE R&D will require active management so as to mitigate the potentially negative economic and national security impacts of globalization. Such active management requires government action.

Conclusions on the Current Situation

The committee offers these conclusions on MSE R&D today:

- **Conclusion 1**
  Globalization of MSE R&D is proceeding rapidly, in line with broader trends toward globalization. As a result of increasing international trade and investment, the emergence of new markets, and the growth of the Internet and the global communications system, MSE R&D in the United States is an internationalized activity with a diverse set of international partners.

- **Conclusion 2**
  The globalization of MSE R&D is narrowing the technological lead of the United States.

- **Conclusion 3**
  At this stage, economic analysis is limited by a dearth of data and by the lack of a comprehensive empirical framework. Although available evidence suggests that the globalization of MSE R&D has had a limited impact on the U.S. economy so far, the medium-term impact is highly uncertain. A positive impact will depend on globalized MSE R&D leading to increased U.S. productivity and contributing positively to U.S. domestic innovation.

Conclusions on the Current Situation (contd.)

- **Conclusion 4**
  The results of MSE R&D continue to enhance U.S. national security and homeland defense by adding improved materials capabilities to the weapons and protective systems used by today's war fighter. The evolution of materials research in the United States and abroad will affect the nation's ability not only to defend against emerging threats of the 21st century but also to ensure a healthy economy as a basic underpinning of national security. Because knowledge and the intellectual capacity to generate new knowledge are proliferating across the world, because innovation and development cycles are becoming shorter, and because U.S. dependence on foreign sources of innovation is increasing, the lead in critical technologies enjoyed thus far by the U.S. defense and intelligence communities will be seriously eroded without mitigating action.

- **Conclusion 5**
  In response to the globalization of MSE R&D, it is the task of public policy to minimize the risks and maximize the benefits to ensure the ongoing U.S. innovation that is essential to the nation's economy and national security, and to facilitate continued access to the new knowledge generated by MSE R&D.

Globalization of
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Conclusions on the Current Situation (contd.)

- **Conclusion 6**
  It is in the long-term interest of the United States to participate in international partnerships in MSE R&D and thereby ensure U.S. access to cutting-edge knowledge and technology.

- **Conclusion 7**
  There is a need to maintain a robust U.S. MSE R&D infrastructure whereby materials problems can be addressed and solved, and the solutions verified, from laboratory through pilot scale.

- **Conclusion 8**
  The MSE education system, including K-12 mathematics and science education, will have to evolve and adapt so as to ensure a supply of MSE professionals educated to meet U.S. national needs for MSE expertise and to compete on the global MSE R&D stage. The evolution of the U.S. education system will have to take into account the materials needs identified by the federal agencies that support MSE R&D as well the needs of the materials industry.

Recommendations

Recommendation on Developing a National Strategy

To maximize the benefits for the United States of the globalization of materials science and engineering research and development (MSE R&D), the federal government should create a well-defined and coordinated national strategy to manage the development of and access to strategic MSE knowledge and technology in a global framework. Particular emphasis must be given to defining and achieving MSE R&D goals for ensuring a strong 21st century U.S military and a secure U.S. homeland.

In building a U.S. national strategy for effective development and use of MSE R&D, the following elements should be considered:

- Identifying in MSE R&D across the defense services and other relevant national security agencies programmatic linkages that will facilitate a coordinated approach to answering critical questions across the subfields of MSE and assessing the readiness of R&D programs to do so; analyzing domestic readiness to provide critical MSE capabilities; and developing recommendations on the role that international and transnational MSE R&D might play;
- Defining (1) immediate priorities for which programmatic directions are clear and (2) next steps, which will require development of a roadmap as a prelude to determining relevant MSE R&D programs;
- Including as participants a comprehensive range of stakeholders and decision makers from the defense, homeland security, and intelligence communities and obtaining significant input from and coordinating with the wider federal science and engineering agencies—including the National Science Foundation, the Department of Energy, NASA, and so on; and
- Soliciting independent advice from academia, industry, and other experts, as required—perhaps with the participation of the Defense Science Board—and obtaining input from industry on policies and incentives that could encourage proactive industry strategies for sustaining a strong MSE R&D base in the United States.

Globalization of
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Recommendations (Contd.)

Building a national strategy to ensure U.S. leadership in and access to advances in globalized MSE R&D will require specific efforts, and in this connection, the committee offers five more recommendations:

Recommendation on Gathering Better Data

U.S. data collection efforts and forecasting systems should be strengthened in order to monitor trends in the offshoring of MSE R&D and the growth of MSE R&D worldwide.

Recommendation on Improving Monitoring

The Department of Defense should build on existing capacities to monitor, assess, and promote access to developments in MSE R&D across the globe with a strategic view to underpinning the maintenance of U.S. leadership and security. In addition, existing U.S. government internal systems for strategic and critical technology analysis, management, and integration should be strengthened. Modern database and communication systems for use in identifying synergies across the defense services should be developed.

Recommendation on Conducting Comprehensive, Expedited Benchmarking

An expedited benchmarking study, similar to *Experiments in International Benchmarking of U.S. Research Fields* (National Academy Press, Washington, D.C., 2000), should be conducted immediately to assess the relative global position of the United States in MSE R&D.

Recommendations (Contd.)

Recommendation on Establishing Long-Term Security Needs and Challenges

The Department of Defense should strengthen current systems for establishing clearly the materials needs of the 21st century war fighter as well as those essential to achieving national and homeland security priorities. Efforts in this regard should focus not on meeting the shorter-term acquisition needs of the military, but rather on identifying and prioritizing the longer-term questions and challenges that MSE R&D will have to address in order to meet identified long-term U.S. security needs.

Recommendation on Reviewing Regulatory Regimes Export Controls –

A systematic review of the rationale for and the impacts of U.S. government regulation of the transfer of knowledge and innovation across borders within the framework of globalized MSE R&D should be carried out by a government task force of representatives from the relevant agencies, with input from academia and industry.

Final Remarks

- Addressing the needs that became clear during the course of this study, mitigating the risks identified, and answering outstanding questions require the nation's public policy makers to formulate a national response strategy to the globalization of MSE R&D.
- The recommendations provide a framework for a robust strategy that will assure a positive impact and outcome for the United States and the nation's continued access to current MSE R&D.
- The framework is based on a series of initiatives that will benchmark MSE R&D in the United States; define the MSE R&D challenges and opportunities in meeting 21st century national security needs; manage an IP regulatory framework that supports U.S. MSE innovation in a globalized environment; and build a national infrastructure to support a global role for the United States.
- The challenge here is multidimensional and intrinsically interconnected across many agencies within the federal government.

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

August 2005

Globalization of Materials R&D: Time for a National Strategy—*Summary*

NATIONAL MATERIALS ADVISORY BOARD

Background

Materials Science and Engineering (MSE) R&D is spreading globally at an accelerating rate, in line with broader globalization trends. As a result, the relative U.S. position in a number of MSE subfields is in a state of flux. To understand better this trend and its implications for the U.S. economy and national security, the Department of Defense (DOD) asked the NRC to assess the status and impacts of the global spread of MSE R&D. This report presents a discussion of drivers affecting U.S. companies' decisions about location of MSE R&D, an analysis of impacts on the U.S. economy and national security, and recommendations to ensure continued U.S. access to critical MSE R&D.

Findings

U.S. MSE R&D is an international activity with a diverse set of partners. The global spread of MSE R&D is narrowing U.S. technological leadership. Nevertheless, the impact of this trend on the U.S. economy has been limited so far, and future impacts are likely to differ across materials subfields. The United States can gain from MSE R&D globalization if it fosters increased productivity, efficiency, and a capacity for innovation.

The results of MSE R&D continue to enhance U.S. national security and homeland defense. The global proliferation of this R&D, however, means that the lead in critical technologies now enjoyed by U.S. defense and intelligence efforts will be seriously eroded without mitigating action.

It is the task of public policy to minimize the risks and maximize the benefits of MSE R&D globalization by facilitating continued access to the products of that R&D. A positive impact can be achieved if both the U.S. government and private sector effectively integrate foreign or joint R&D into domestic R&D programs. A critical element of this effort is the ability of the United States to attract top researchers to both support this exploitation and help continue a strong domestic R&D effort. Maintaining access to as well as generating cutting-edge science and technology is essential if the nation is to sustain economic leadership and a strong national defense capability.

Recommendations

Maintaining access to MSE R&D will require active management. The federal government should create a well-defined and coordinated national strategy to manage the

development of and access to strategic MSE knowledge and technology in a global framework. The strategy should facilitate a coordinated approach across defense and intelligence agencies to addressing critical MSE questions; define priorities and develop an MSE R&D roadmap; include a comprehensive range of stakeholders and decision makers; and solicit independent advice from academia, industry, and other experts.

Development of a national strategy will also require a better understanding of current trends in MSE R&D. Better data and new analytical tools will be required. DOD should also strengthen its existing technology forecasting and monitoring activities and expand its efforts to identify critical technology worldwide in order to monitor, assess, and promote access to global developments in MSE R&D. In addition, an expedited benchmarking study should be conducted to assess the relative global position of the United States in MSE R&D.

A thorough understanding of what knowledge is needed for national security purposes is also essential. Current DOD systems for establishing the materials needs for the 21st century warrior and other essential priorities should be strengthened. This effort will benefit from the highest level of coordination and cooperation within DOD and between the relevant federal agencies; ongoing assessment of existing critical technology lists; and definition of longer-term goals for MSE R&D.

It is important that U.S. regulatory regimes do not unreasonably impede the participation of U.S. researchers in international R&D activities or of foreign researcher's in domestic research. It is in the long-term interest of the United States to participate in international partnerships in MSE R&D. It is also necessary to ask whether there are technologies to which the nation must secure access but does not need to control, and what the effects would be on the nation's export control regime. Access to cutting-edge knowledge can be achieved more effectively if the United States becomes the most active player in global MSE R&D. A systematic review of the rationale for and impacts of U.S. government regulation of the transfer of knowledge and innovation across borders within the framework of global MSE R&D should be carried out.

Finally, the U.S. educational system, including K-12 math and science education, will have to evolve and adapt in order to produce MSE professionals to meet national needs. In addition, maintaining U.S. expertise and leadership in MSE R&D will require a robust national research infrastructure.

The challenge presented by the globalization of MSE R&D is, multidimensional, significant, and intrinsically interconnected across many federal agencies. A national strategy to ensure U.S. leadership in and access to advances in global MSE R&D should be established and implemented as a national priority.

For Further Information

Copies of *Globalization of Materials R&D: Time for a National Strategy* can be obtained from the National Academy Press, 2101 Constitution Avenue, N.W., Washington, DC 20418, 201-334-3313, <http://books.nap.edu/>.

Support for this project was provided by the Department of Defense. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the sponsors. More information about the National Materials Advisory Board can be found at <http://www7.nationalacademies.org/nmab>.