Globalization could threaten U.S. access to advances in materials science and engineering.

Globalization of Materials Research and Development

Peter Bridenbaugh and Michael Moloney

Peter Bridenbaugh

Michael Moloney

The media these days are filled with talk of offshoring and outsourcing. The continued globalization of research and development (R&D) and the proliferation of information technology and global communications are being driven by large trends, such as the impact of twenty-first century technology and increased international and transnational industrial and economic activity. Under the auspices of the National Research Council National Materials Advisory Board, and sponsored by the U.S. Department of Defense, a new study, *Globalization of Materials R&D: Time for a National Strategy*, was conducted to examine these issues and assess how they might affect continued U.S. access to the best of materials science and engineering (MSE) R&D. The study committee defined globalization as the worldwide expansion of MSE knowledge-creation centers as a result of U.S. and non-U.S. industry and government investments, as well as worldwide collaboration facilitated by information technology.

The study had four goals: (1) to assess the current status of MSE R&D from a global perspective; (2) to identify the drivers of U.S. companies' decisions to locate materials research in the United States or abroad; (3) to assess

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Peter Bridenbaugh is retired executive vice president, automotive, Aluminum Company of America, chair of the Committee on Globalization of Materials Research and Development, and an NAE member. Michael Moloney is a senior program officer, National Materials Advisory Board, National Research Council.

the impact of the globalization of MSE R&D on the U.S. economy and national security; and (4) to recommend actions to ensure continued U.S. access to critical MSE R&D.

Globalizing Trends

Information from the National Science Foundation (2004), the results of a survey of industrial R&D by the Economist Intelligence Unit (2004), and the results of a poll of MSE practitioners carried out for this study all show that globalization has led to an increase in both transnational, academia-led R&D with international academic and industrial collaborators and transnational, corporation-led R&D with foreign affiliates of U.S. corporations, foreign academics, or foreign corporations. The data show that companies are being driven to globalize R&D activity for a number of reasons: (1) access to expertise; (2) mitigating the impacts of regulatory regimes; (3) proximity to new international customers; and (4) cost savings. The risks of investing in overseas corporate R&D vary but can include concerns about the ownership of intellectual property and the security of trade secrets, as well as concerns about the rule of law and democratic institutions. Academic researchers are also participating in global MSE R&D by seeking out domestic or international partners that can advance their research priorities, by participating in international conferences, and by adopting information technology for sharing R&D results on a global scale.

Our strategic lead in materials-related technology, and perhaps other technologies, is clearly threatened.

The effects of globalization on U.S. leadership in MSE R&D vary by field or subfield. For instance, in composites, U.S. leadership has declined to the point that we may no longer be able to exploit the promise of new composites. Leadership in the subfield of magnetic materials is mixed; the United States leads in some critical areas and is among the leaders in other areas. In metallurgy R&D, the United States appears to be losing its leadership role, and all indications are that this trend will continue. The situation in electronic and optical-photonic materials is mixed, with the United States leading in some areas but not in others. Currently, U.S. scientists working on superconducting materials are at the cutting edge of R&D on nearly all fronts; however, other countries share the lead or have surpassed us in applications. In catalyst technology, there has been a continued decline in U.S. leadership. In nanomaterials and nanotechnology, as measured by the number of corporations engaged in the subfield, the United States leads, but it is too early to say which, if any, region of the world will emerge as a clear leader as this field matures. Because nanotechnology is essential to many electronic and photonic materials and devices, the U.S. position in these subfields is interconnected.

Surveys of patents and recent literature suggest that, even though MSE R&D is emerging at an accelerating rate in countries not previously known as centers of materials expertise, the United States remains either the world leader or among the world leaders in most MSE subfields. But the European Union and the Asia-Pacific region, notably Japan and, recently, China, are challenging traditional U.S. leadership. Global activity in all areas of MSE is increasing significantly in Asian countries that were not active in these fields before. Although it is difficult to say how the situation will evolve, the overall trend is clear. In keeping with broad trends toward globalization, the globalization of MSE R&D is proceeding rapidly and the technological lead of the United States is narrowing. The loss of U.S. leadership in several areas of materials research where it has traditionally been dominant is a real possibility.

Impacts for the United States

The proliferation of technologies and capabilities, at the very least, will complicate the analysis of potential threats and challenges to the United States and, at worst, will allow potential adversaries to gain the advantage in strategic fields. Although the United States might also gain some advantages from exploiting new technologies that might emerge as a result of increased global activity, the strategic one- to two-generation lead in materials-related technology, and perhaps other technologies, is clearly threatened.

Economic Impact

The overall economic impact of the globalization of MSE R&D has been limited so far, although analysis is difficult because of a lack of data and the absence of a robust, analytical framework. The economic impact is also likely to differ by subfield. For example, the United States has already lost its competitive advantage in catalysts but so far maintains its lead in semiconductor research. The overall economic impact of globalization will depend on how these trends evolve and on the future relative contributions of materials subfields to the U.S. economy.

On balance, the United States could gain from the globalization of MSE R&D, but only if the country positions itself strategically in the new R&D environment and U.S. companies can gain new advantages by integrating domestic and global R&D results into final products. This outcome requires creating conditions at the private and public levels that enable U.S. firms to increase their productivity, efficiency, and innovative capacity. U.S. companies will then be able to take advantage of foreign R&D and international R&D relationships by integrating them fully and effectively into their domestic R&D programs—assuming they have maintained these capabilities.

Impact on National Security

Globalization of MSE R&D will also affect our national security. U.S. security forces in the twenty-first century will have to communicate faster, more reliably, and on a global scale. New threats to national and homeland security will require new detection methods, and new tasks will require new weapons and new materials for new and better delivery platforms. New systems will have to be multifunctional, self-diagnostic, self-healing, low cost, low maintenance, environmentally acceptable, and highly reliable. MSE R&D that meets those needs will certainly improve our national security and homeland defense.

The evolution of materials research in the United States and abroad will affect the nation's ability not only to defend against emerging threats, but also to ensure that the economic underpinnings of national security remain healthy. As knowledge and the intellectual capacity to generate new knowledge proliferate across the world, as innovation and development cycles become shorter, and as U.S. dependence on foreign sources of innovation increases, the lead in critical technologies enjoyed thus far by U.S. defense and intelligence communities will be seriously eroded unless mitigating actions are taken.

The emergence of new centers of high-value research across the globe has created an international market-like demand for the best and brightest students and experts, challenging the ability of the United States to attract top researchers. Any decrease in the supply of non-U.S. experts directly involved in U.S. research and innovation, combined with the acknowledged difficulty of attracting U.S. students to MSE, will put a strain on the supply of top scientists and engineers capable of conducting R&D necessary for economic growth and national security. A loss of expertise will diminish not only the value of the U.S. research output, but also, in the long term, the nation's capacity to recognize, understand, and exploit research results from elsewhere.

Increasing dependence on foreign sources of innovation could jeopardize the U.S. lead in defense and intelligence technologies.

Recommended Actions

The globalization of MSE R&D could have a significant positive impact for the United States, but the risks of a negative impact remain substantial. Even if great efforts are made to maintain control of U.S.-generated technologies, knowledge, and capabilities, investments by other governments in their own MSE R&D will challenge the United States' technological lead. The loss of national capacity for MSE research or a decline in the ability of U.S. manufacturing to take advantage of and motivate MSE research or a diminished U.S. military, homeland defense, or intelligence capability would not only damage our national pride or our international image. In a knowledge-based future, the United States will retain its current world economic leadership and its strong national defense and security only if it continues to have access to, and in many cases generate, cutting-edge science and technology. The United States must maintain access to the global output of critical MSE R&D.

Access is only part of the story, however. Integration must also be a priority. But integrating R&D is not easy.

If current trends continue, there is a risk that some of the knowledge generated in MSE R&D abroad will not be absorbed in the United States and that the United States may not have the domestic expertise to recognize foreign innovation and maximize its integration. Maintaining access to current MSE R&D will require active management, which in turn will require a national strategy that allows the United States to take advantage of the benefits of the globalization of MSE R&D.

A protectionist approach might result in the U.S. losing access to superior technologies developed elsewhere.

Developing a National Strategy

A national strategy for the effective development and use of MSE R&D must include several elements. First, there must be a coordinated approach to exploring critical questions in the various subfields of MSE. This will require identifying programmatic linkages among R&D programs of the defense services and national security agencies, assessing the readiness of these R&D programs to provide critical MSE capabilities, and recommending how international and transnational MSE R&D should be integrated into these domestic efforts. Second, there must be a road map that defines immediate priorities and next steps. Third, stakeholders and decision makers from the defense, homeland security, and intelligence communities should coordinate and find synergies with the wider federal science and engineering agencies (including the National Science Foundation [NSF], U.S. Department of Energy [DOE], National Aeronautics and Space Administration [NASA], etc.). Fourth, advice from academia, industry, and other experts should be solicited, as required—perhaps with the participation of the Defense Science Board; and industry should be asked to suggest policies and incentives that would encourage proactive strategies for retaining a strong MSE R&D base in the United States.

A robust national strategy that ensures U.S. access to the results of MSE R&D will require a thorough understanding of current trends in MSE R&D worldwide; the identification of the questions and challenges that must be addressed to meet national economic, defense, and homeland security needs; and a fresh approach to managing regulatory regimes, improving education, and strengthening the infrastructure for U.S. MSE R&D. This will require sufficient information on global MSE R&D activities and effective monitoring, as well as regular benchmarking of the relative status of U.S. MSE R&D.

Currently, data on the global flow of investments in R&D generally, and in MSE R&D specifically, are insufficient. Building a national strategy that ensures U.S. access to MSE R&D will require the collective efforts of various federal agencies to provide better data and new analytical tools to understand the complexities of the R&D globalization phenomenon. Maintaining continuous access to global R&D will require improving U.S. Department of Defense (DOD) forecasting and monitoring systems and expanding capabilities of identifying the development of critical technologies worldwide.

Of course, predicting what new capabilities might be developed from yesterday's research or the particular challenges tomorrow's adversaries might present may be difficult, at best (DSB, 2005; NRC, 2002, 2003). Moreover, the acquisition of technology from another country in the past does not guarantee that the same can be done in the future. Addressing these and other national security concerns will require coordination and cooperation among DOD, NSF, DOE, NASA, the U.S. Department of State, the U.S. Department of Commerce, and others to assess lists of existing critical technologies, contractual arrangements, and R&D funding procedures and to define longer term goals for MSE R&D.

Regulatory regimes can have a significant impact on national policy. They can affect where R&D is performed, determine how intellectual property developed abroad is treated, define export licensing processes that affect the execution of R&D programs, affect the availability of skilled researchers, and provide tax incentives. As MSE R&D becomes increasingly global, public policy makers must ensure that U.S. regulatory regimes do not unreasonably impede the participation of U.S. researchers in international R&D of national importance or the participation of foreign researchers in U.S. research. A review of the nation's regulatory system should include how the system of export controls would be affected by identifying important technologies to which the nation must have access but not necessarily control.

It may be tempting to consider protecting U.S. interests by retreating from the world stage in areas considered critical to national or economic security. A protectionist approach, however, might result in the United States not having access to superior technologies developed elsewhere. The best way to ensure access to cutting-edge knowledge and technology and protect long-term U.S. interests would be for the United States to participate in international partnerships and become an active player in global MSE R&D.

Maintaining a world-class domestic capacity to engage in international MSE R&D, to integrate non-U.S. R&D into U.S. systems, and to monitor and understand global MSE R&D and its impact on U.S. technological leadership will require significant changes in the U.S. MSE educational system. The challenges facing the system include the expanding curricula in MSE departments; the difficulty of attracting high school and university graduates to pursue careers in MSE; and the continuing dependence of graduate programs on foreign students, who are now the objects of intense global competition. The Organisation for Economic Co-operation and Development reports that in 2000 about 40 percent of students in China graduated with engineering degrees, whereas in the United States the figure was about 5 percent (OECD, 2002).

For the United States to maintain its leadership in innovation and a robust national research infrastructure, these trends must be turned around. Efforts could include: promoting MSE as a career choice; helping students overcome deficiencies in K-12 education; meeting the needs of U.S. industry and other actors; providing financial support to encourage U.S. citizens to study materials science; setting minimum competencies for graduate students working on master's degrees in MSE; and improving the balance between large and small MSE departments.

Maintaining U.S. expertise and leadership must be based on a robust research infrastructure wherein materials problems can be addressed and solved and the solutions verified, from laboratory scale through pilot scale. However, the loss of once-dominant industry materials laboratories raises serious questions about where future MSE R&D will take place. The United States can no longer count on the ongoing exploration of new technical areas that could be of interest to business and ongoing monitoring of developments in university and government laboratories. Clearly, this is a serious problem that must be addressed.

Conclusion

Formulating a national strategy in response to the globalization of MSE R&D will present policy makers with multidimensional challenges. Coordinating the activities of so many federal agencies and mobilizing the resources of industry and academia may require the involvement of the Executive Office of the President. The recommendations in the new NRC report (2005) provide a framework for a robust national strategy that could ensure a positive impact for the United States and continued access to current MSE R&D. The framework is based on a series of initiatives to benchmark MSE R&D in the United States; define MSE R&D requirements for twenty-first century national security needs; outline a regulatory framework that supports U.S. MSE innovation in a globalized environment; and maintain a national infrastructure that supports a global role for the United States.

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