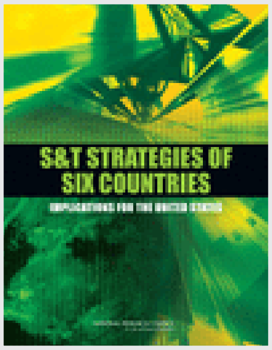

S&T Strategies of Six Countries: Implications for the United States

DETAILS

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IMPLICATIONS FOR THE UNITED STATES

Committee on Global Science and Technology Strategies and Their Effect on U.S. National Security

Standing Committee on Technology Insight—Gauge, Evaluate, and Review

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Preface

In the spring of 2009, the Office of the Chief Scientist, Central Intelligence Agency, and the Defense Warning Office of the Defense Intelligence Agency (DIA) asked the National Research Council (NRC) to review and analyze the science and technology (S&T) advancement strategies of six countries and to judge their likely impact on U.S. national security and competitiveness at present and over the coming 3 to 5 years and 10+ years. The sponsors also asked the NRC for recommendations to the U.S. government based on the study findings.

We wish to express our appreciation to the members of the committee for their diligent and dedicated contributions to the study and to the preparation of this report. The committee's diverse experience contributed greatly to the broad perspective on S&T in the 21st century that is incorporated in this report. The committee is also grateful to the CIA and DIA for their sponsorship and to the intelligence community for its active participation throughout the study. The committee cannot thank the NRC staff members Dennis Chamot, Daniel Talmage, Marguerite Schneider, Kamara Brown, and Shannon Thomas too effusively for their dedication to the study and to the preparation of this report.

C. Dan Mote, *Chair*
John Gannon, *Vice Chair*
Committee on Global Science and Technology Strategies and Their Effect on U.S. National Security

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's (NRC's) Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

R. Stephen Berry, NAS, Franck Institute,
Arthur I. Bienenstock, Stanford University,
Vinton G. Cerf, NAE, Google, Inc.,
Diane E. Griffin, NAS, IOM, Johns Hopkins Bloomberg School of Public Health,
Richard Johnson, Arnold & Porter, LLC,
Jonathan D. Moreno, University of Pennsylvania Health System,
R. Byron Pipes, NAE, Purdue University, and
Paul Saffo, Saffo.com.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Julia Phillips (NAE), Sandia National Laboratories. Appointed by the NRC, she was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Contents

Acronyms and Abbreviations

A*STAR	Agency for Science, Technology and Research (of Singapore)
BMD	ballistic missile defense
BPD	barrels per day
BRIC	Brazil, Russia, India, and China
CIA	Central Intelligence Agency
CNPq	Conselho Nacional de Desenvolvimento Científico e Tecnológico (Council for Scientific and Technological Development)
CRS	Congressional Research Service
CSIR	Council of Scientific and Industrial Research (Government of India)
CSTP	Council for Science and Technology Policy (Government of Japan)
DAE	Department of Atomic Energy
DIA	Defense Intelligence Agency
DOD	Department of Defense (United States)
DPJ	Democratic Party of Japan
DST	Department of Science & Technology (Government of India)
DSTA	Defence Science and Technology Agency (Government of Singapore)
EDA	electronic design automation
ERA	Emergency Reaction to Accidents
FDI	foreign direct investment
FINEP	Financiadora de Estudos e Projetos (Financier of Studies and Projects)
FYP	five-year plan
GCI	global competitiveness index

GDP	gross domestic product
GERD	gross expenditure on research and development
GET-UP	Growing Enterprises with Technology Upgrade (Singapore)
GLONASS	Global'naya Navigatsionnaya Sputnikovaya Sistema (Global Navigation Satellite System)
GNP	gross national product
GPS	global positioning system
GSLV	Geosynchronous Satellite Launch Vehicle
GWe	gigawatt-electric
HTI	High Tech Indicator
IC	intelligence community
IED	improvised explosive device
IGS	information gathering satellite
IITs	Indian Institutes of Technology
IMD	International Institute for Management Development
IMF	International Monetary Fund
INCT	Instituto Nacional de Ciência e Tecnologia (National Institute of Science and Technology)
INSAT	Indian National Satellite System
IP	intellectual property
ISSCC	International Solid State Circuits Conference
IT	information technology
ITC	innovative-technological centers
JBRICS	Japan, Brazil, Russia, India, China, and Singapore
KAM	Knowledge Assessment Methodology
KIP	Knowledge Innovation Program
MDA	model-driven architecture
MLTP	Medium and Long Term Plan for S&T
MTI	Ministry of Trade and Industry (Government of Singapore)
MRI	magnetic resonance imaging
MWe	megawatt-electric
NAE	National Academy of Engineering
NIAC	national information analytical center
NIC	National Intelligence Council (of the United States)
NIE	National Intelligence Estimate
NISTADS	National Institute of Science, Technology and Development Studies
NISTEP	National Institute of Science and Technology Policy
NRC	National Research Council
NSF	National Science Foundation
OECD	Organisation for Economic Co-operation and Development
PACTI	Plano de Ação, Ciência, Tecnologia e Inovação para o Desenvolvimiento Nacional (Action Plan on Science, Technology and Innovation for National Development)
PDM	product data management
PHWR	pressurized heavy-water reactor

PPP	purchasing power parity
PRC	People's Republic of China
PSA	Office of the Principal Scientific Adviser (India)
PV	photovoltaic
PWR	pressurized water reactor
QDR	Quadrennial Defense Review
R&D	research and development
RD&I	research, development, and innovation
RIEC	Research Innovation & Enterprise Council
S&T	science and technology
SARS	severe acute respiratory syndrome
SERC	Science and Engineering Research Council (of Singapore)
SPRING	Standards, Productivity, and Innovation Board
ST&I	science, technology, and innovation
STEM	science, technology, engineering, and mathematics
TIGER	Technology Insight—Gauge, Evaluate, and Review
UAV	unmanned aerial vehicle

Summary

Following World War II, the United States began one of the world's first initiatives to provide government support for science and technology (S&T) research with the goal of producing innovations that would enhance the health, security, and economic well-being of all Americans. The success of this and other initiatives, which in subsequent decades propelled the United States to its greatest-ever prosperity, has been a model for other countries seeking to use S&T development to achieve greater wealth and power.

An increase in global access to goods and knowledge is transforming world-class S&T by bringing it within the capability of an unprecedented number of global parties who must compete for resources, markets, and talent. In particular, globalization has facilitated the success of formal S&T plans in many developing countries, where traditional limitations can now be overcome through the accumulation and global trade of a wide variety of goods, skills, and knowledge. As a result, centers for technological research and development (R&D) are now globally dispersed, setting the stage for greater uncertainty in the political, economic, and security arenas.

These changes will have a potentially enormous impact for U.S. national security policy, which for the past half century has been premised on U.S. economic and technological dominance. As the U.S. monopoly on talent and innovation wanes, arms export regulations and restrictions on visas for foreign S&T workers are becoming less useful as security strategies. The acute level of S&T competition among leading countries in the world today suggests that countries that fail to exploit new technologies or that lose the capability for proprietary use of their own new technologies will find their existing industries uncompetitive or obsolete. The increased access to information has transformed the 1950s paradigm of "control and isolation" of information for innovation control into the current one of "engagement and partnerships" between innovators for innovation creation. Current and future strategies for S&T development need to be considered in light of these new realities.

This report of the Committee on Global Science and Technology Strategies and Their Effect on U.S. National Security analyzes the S&T strategies of Japan, Brazil, Russia, India, China, and Singapore (JBRICS)—six countries that either have undergone or are undergoing remarkable growth in their S&T capabilities—for the purpose of identifying unique national features and how they are utilized in the evolving global S&T environment. It evaluates the implications for U.S. national security of each of the JBRICS countries' S&T strategies for the near and middle terms; identifies the best indicators of the six countries' strategic priorities; and predicts the likelihood that they can achieve their goals, especially in high-impact fields such as energy, neuroscience, nanoscience, information technology, and materials science, and within what timeframes. Through such analyses the United States can prepare for and react to global changes in S&T environments and consequently preserve and enhance its own security and competitiveness in the 21st century.

Many factors affect the likelihood of achieving national S&T goals, including the coupling of socioeconomic and cultural drivers, the rapid advancement of technological development, the globalization of R&D, the opaqueness and the resulting unpredictability of programs, and simply countries' available resources, priority setting and execution, disruptions, and other internal and external factors. Confidence in the three- to five-year forecasts of S&T capability is reasonably high but decreases to speculation beyond five years.

The best indicators of progress toward achieving national goals are country specific and must reflect both traditional and nontraditional factors. Traditional indicators are quantitative measures of S&T investment, activity, and outcomes such as patents per capita, S&T investment as a percentage of gross domestic product (GDP), the fraction of national research expenditures made by industry, and the number of start-up companies. A visualization of the JBRICS countries according to a selection of such S&T innovation-related indicators is shown in Figure S-1. Nontraditional indicators emerging from cultural contexts are country specific. They are essential to understanding

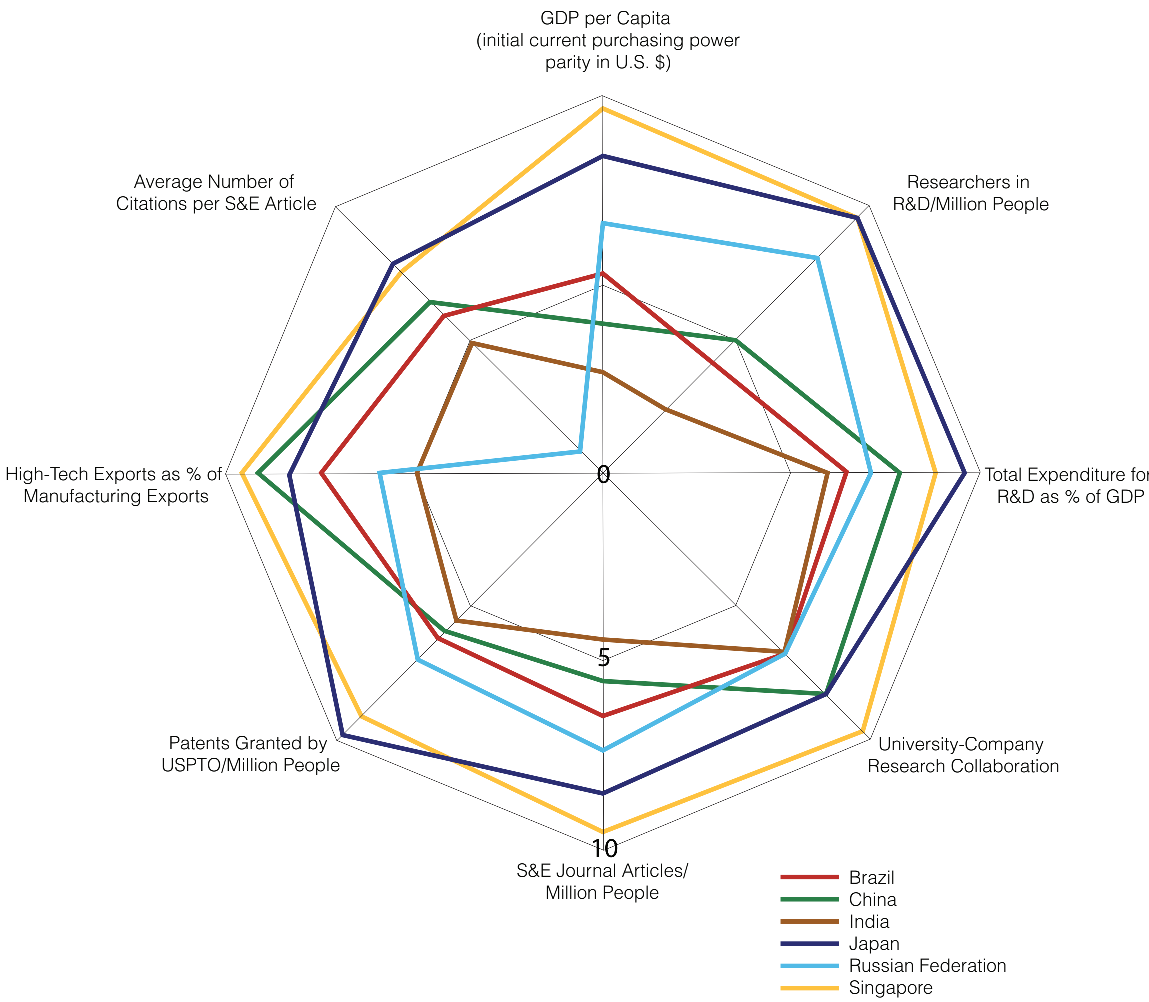

FIGURE S-1 Comparison of supply and output indicators in JBRICS countries using the Knowledge Assessment Methodology. SOURCE: World Bank. 2009. Knowledge for Development (K4D) Website: Custom Scorecards (KAM 2009). Tool available at http://info.worldbank.org/etools/kam2/KAM_page3.asp?default=1. Last accessed June 14, 2010.

each country's S&T innovation environment and especially to predicting its future change. The cultural contexts of Brazil, India, Japan, and Russia have slowed their S&T innovation developments and will continue to do so in the near to mid terms. No single set of common indicators was found by the committee to provide a complete assessment of progress toward goals for all countries.

One of the better indicators of a country's ability to achieve its S&T innovation goals is its ability to effect the requisite cultural changes. Among the six countries studied, China and Singapore have demonstrated a high capability to make the needed changes in cultural norms, and Russia has demonstrated the least capability, which will most likely delay or block its ability to achieve its S&T innovation goals. Furthermore, the S&T innovation environments of the more successful countries possess both top-down (i.e., led by government) and bottom-up (i.e., led by individuals and organizations) drivers of change. Among the JBRICS countries, China and Singapore also are the furthest along in this direction, and the likelihood of their continued, substantial progress is therefore high.

The national S&T innovation environment that has been a hallmark of the United States since World War II, and the model for other nations, is evolving into a new, 21st-century, global innovation environment in which R&D talent, financial resources, and manufacturing systems are integrated but geographically dispersed. In this context, the S&T strategy of a country has implications for its military capabilities both through wide-ranging, dual-use technology developments and through priorities given to developing those military capabilities for national use and for sale.

JBRICS investment in military modernization, a priority in China, Russia, India, and Singapore, and less so in Brazil and Japan, has varying implications for U.S. national security. China and India credibly integrate their goals for military modernization into broader, overriding goals for economic development, and their military capabilities are increasing. Russia views increased military strength as a counter to its declining economic, political, and diplomatic stature in the world, which is potentially more troubling. Singapore's and Brazil's military goals are consistent with transparent national plans and are not a significant natural security concern for the United States.

On the basis of its findings regarding implications of identified national S&T strategies in the JBRICS countries, the committee makes a number of recommendations to the U.S. government and the intelligence community. Its key recommendations are listed below; additional findings and recommendations are presented in Chapters 3 through 10. The recommendations highlight current observations and suggest that, at a minimum, further tracking of the best indicators be undertaken to verify the countries' middle- and long-term S&T strategies and achievements.

Key Recommendation. Because a successful global S&T innovation environment portends future prosperity and security for all countries, monitoring the transformation from a national to a global S&T innovation environment should be undertaken on a regular basis for the United States and all countries of interest. Because this transformation can take place before a national S&T environment is fully developed, monitoring should be conducted independent of a country's current achievement. **(Recommendation 10-1)**

Key Recommendation. The transfer of intellectual property by multinational corporations into domestic companies through S&T activities should be monitored in key countries, particularly India and China. The United States could join with Japan, and possibly the European Union, to establish a united front against such practices. **(Recommendation 10-2)**

Key Recommendation. The United States should assess its own preparation for, and transformation to, a successful global S&T innovation environment to ensure that it remains in a preeminent S&T position for continued prosperity and national security. Specific areas for assessment should include global exchanges in education and R&D talent, international as well as national recruitment of R&D talent, multinational corporate collaborations, and public policies that facilitate or restrain the leadership of the United States in global S&T innovation. **(Recommendation 10-3)**

Key Recommendation. For each country of interest, the United States should identify country-specific measures of S&T innovation environments, including nontraditional indicators that are appropriate for targeted technologies and developments. The United States should monitor each country's capacity to facilitate the cultural changes needed to achieve its global S&T innovation environment. These indicators are especially important for predicting future changes in S&T innovation environments. **(Recommendation 10-4)**

Key Recommendation. The most successful global S&T innovation environments will recruit S&T talent into attractive positions with excellent facilities and research support. The United States should track the quality and availability of research facilities and research support as a significant indicator of any country's attractiveness to the world's S&T talent. **(Recommendation 10-5)**

Key Recommendation. The United States should continue to gauge the efficiency of research, measured by the effective uses of research talent and research facilities, which portends the future of a county's innovation environment. Efficiency ultimately guides the use of research talent and facilities. For instance, the monitoring of non-research responsibilities of scientists (such as administration and proposal writing) and the quality of research infrastructure could be incorporated into measures of efficiency. Highly efficient S&T systems support the most attractive research careers for talented S&T contributors. **(Recommendation 10-6)**

Key Recommendation. The U.S. government should assess, as a matter of urgency, the national security implications of the continuing global S&T revolution and the global dispersion of R&D. It should evaluate the impact of the decline in U.S. academic competitiveness at the primary and secondary levels, as pointed out in the 2007 report *Rising Above the Gathering Storm*, especially with regard to the sciences. Equally important, the assessment should seek mechanisms for sustainable U.S. government collaboration with the international community to uncover and exploit potential scientific and technological breakthroughs, wherever they occur, and to contain whatever threats they may portend. **(Recommendation 9-1)**

1

Introduction

The United States, with less than 5 percent of the world's population and 23 percent of the world's total gross domestic product, can maintain a secure homeland and growing prosperity for its citizens only through high-value and globally competitive achievements in science and technology (S&T) and through nurturing an S&T environment that implements innovations with superior efficiency and effectiveness. Our globally connected and rapidly changing world has resulted in a more diverse mixture of markets, talents, competitors, and contributors for the next generations of scientific discoveries, destructive technologies, and innovation environments. Change is accelerating due to the explosive growth and accessibility of information, the increasing numbers of highly skilled scientists and engineers engaged in research and development (R&D), and the increasing number of countries investing in and capable of contributing to R&D.

In light of the growing competition for dominance in global S&T markets, the S&T strategies and innovation environments of Japan, Brazil, Russia, India, China, and Singapore (JBRICS) were selected for analysis in this report. These countries vary in their historical and cultural contexts, in the resources on which they can depend, and in their specific S&T objectives. Thus, each country has unique priorities for investment. However, they share the common goal of strengthening their S&T innovation environment, which encompasses educational systems, social networks, funding mechanisms, strategic partnerships, and other formal and/or informal infrastructures that support technology creation. Each country, regardless of its past success, will need to leverage global markets and attract talent from inside and outside its borders to achieve or maintain S&T leadership.

Today, the national S&T policies of the United States are rooted in recommendations from the Vannevar Bush report, *Science The Endless Frontier*, which was presented to President Truman 60 years ago (Bush, 1945). Bush proposed strategies for nurturing and utilizing S&T advances to benefit U.S. national security, and for improving the health and prosperity of the U.S. people. The founding of the National Science Foundation, the National Institutes of Health, and other agencies, and the assignment of responsibilities in basic research, applied research, and industrial development to universities, industry, and the national laboratories were called out in this report. The directions taken as a result of this report, and the revisions to them over the decades, have been remarkably effective at securing and enhancing a leadership position for the U.S. S&T enterprises, to the great benefit of the country.

However, much has changed in the world during the past 60 years. The global science, technology, and innovation (ST&I) environments are largely open, with easy and inexpensive access to information for a greatly expanding number of countries and people who will participate in advanced S&T creation, innovation, and commercialization. The "control and isolation" of information strategy of the 1950s that restricted access to information that was deemed critical to national security and economic competitiveness has broken down in several important areas. Travel restrictions for foreign nationals, export control policies, and the Department of Commerce's control list are manifestations of this earlier policy. However, for at least the past decade, the explosion of access to the Internet and the increase in the conduct of scientific and engineering research outside the United States have increased access to information for people and countries alike. When coupled with the increasing pressure to lead the introduction of innovative products into the global marketplace, this increased access to information has flipped the paradigm from "control and isolation" of information for innovation control to "engagement and partnerships" between innovators for innovation creation. Multinational corporations are locating facilities globally for R&D purposes in addition to traditional manufacturing and sales functions because of the available talent in the workforce, the large potential for market growth, and the high-performance spirit of opportunity in these regions. The expansion of multinational corporate facilities for development and, to a lesser degree, for research is occurring largely outside the United States. Even with its very large R&D investments, the United States does not lead all S&T fields (e.g., biofuels, wind and solar energy technologies, and high-speed rail transport) and will focus its leadership efforts in fields such as biosciences, information, and communication, among others. No matter what innovation policies the United States adopts, the competition for global leadership in S&T can only intensify in the future.

The success of U.S. national S&T strategies through the Cold War has verified the importance of having a policy for protecting national security and for facilitating economic prosperity. "Getting it right" relative to competitor countries matters. History verifies that "getting it wrong" also matters. Because global security and economic competitiveness in 2010 are dissimilar to those of 60 years ago, an understanding of the national S&T strategies and innovation plans of competitor countries is needed to critically assess the United States' relative competitiveness today and more importantly in the future. It is hoped that this report will provide snapshots of the S&T plans of six countries that have employed and are employing successful S&T strategies, so that they may provide insight into the United States' role in today's competitive environment and contribute to an assessment of U.S. security within that environment.

BACKGROUND AND REPORT FOCUS

This is the eighth report in a series developed under the guidance of the National Research Council (NRC) Standing Committee on Technology Insight—Gauge, Evaluate, and Review (TIGER) and sponsored by the Defense Intelligence Agency's Defense Warning Office (NRC, 2005, 2006, 2008a,b, 2010a,b,c). As with the earlier studies, sponsorship of the current report was a result of discussions between the standing committee and the U.S. intelligence community (IC). The overall series is intended to assist the IC in identifying global technology trends that may affect U.S. national security interests and future U.S. warfighter capabilities.

The S&T strategies and innovation environments of Japan, Brazil, Russia, India, China, and Singapore, or JBRICS, were selected by the sponsor for analysis with regard to their potential impact on U.S. national security. Box 1-1 shows the statement of task for the study. This report of the Committee on Global Science and Technology Strategies and Their Effect on U.S. National Security attempts to describe and evaluate the overall effectiveness of the strategies pursued by each country, and to suggest ways in which the United States should engage with these countries to enhance its own awareness and capabilities. It should be noted that this report does not include analysis of U.S. S&T strategies or the consequences to its national security of U.S. indebtedness. In addition, the committee found that most plans of the six countries it studied do not have a 10-year outlook, and so it was not able to comment on that timeframe.

POSSIBLE IMPLICATIONS FOR U.S. NATIONAL SECURITY

To varying degrees, the S&T strategies of all the JBRICS countries have significant implications for U.S. national security. All six nations have concluded that their economic competitiveness is a core national security issue and seek to improve and secure their economic well-being through S&T innovation. The increasing number of participants in the international S&T dialogue poses opportunities and challenges that did not exist 25 years ago.

BOX 1-1
Statement of Task

An ad hoc committee will examine the science and technology (S&T) strategies of Brazil, Russia, India, China, Japan, and Singapore and the relevance of those strategies to U.S. national security. The committee will compare and contrast U.S. S&T strategy planning by federal and nonfederal sources to that of the selected nations and evaluate the implications of any differences for U.S. national security strategy.

Specifically, the committee will:

- Assess key foreign national S&T planning—derived from various national position documents—with special relevance to U.S. national security objectives, evaluate the current, mid-term (3-5 years), and long term (10+ years)* strategies of each, and estimate the expected timeline for the achievement of national S&T goals.
- Identify potentially high-impact areas being pursued by the identified countries (possibly including advanced energy technology, advanced physics, neuroscience, or nanoscience) and identify the potential impact of these areas on national security.
- Recommend nation-specific indicators for each country that could be used to effectively monitor progress in high-impact research. These could include:
    - National research priorities and drivers
    - Funding sources (government, industry) and allocation across fields
    - Financial and human resource allocation
    - Intellectual property (e.g., published papers, patents, and rate and distributional changes thereof)
    - Management: overall policy, work force planning, and mechanisms of execution
    - Other internal and external factors impacting strategy (e.g., global financial climate, demography, environmental issues, incentives for success, and penalties for failure)
- Analyze relationship between foreign S&T strategy and military capability
- Offer key recommendations to the U.S. government and the IC on the application of the identified strategies to the United States

*The committee found that most plans of the six countries it studied do not have a 10-year outlook, and so it was not able to comment on this timeframe.

As a result of these countries' S&T strategies and of the current climate of free-flowing and inexpensive access to information, maintaining scientific and technological assets and preventing technological surprise will continue to be a major challenge for the U.S. government and its intelligence community.

REPORT ORGANIZATION

This report covers the S&T strategies of the JBRICS countries and the relevance of those strategies to U.S. national security. Chapter 2 outlines the methodology developed by the committee used to create the report. Chapters 3 through 8 describe the strategy and goals of each of the six selected countries, and consider other significant factors that affect each nation's innovation environment. Each of these chapters ends with a net assessment of the country's current progress and predicts advancement in key technology areas relevant to U.S. national security. These chapters also highlight unique, nation-specific metrics that can be used to track each country's progress toward achieving its goals and points out key observations and implications for U.S. national security. Chapter

9 provides a condensed analysis of the implications that S&T development in the JBRICS countries might have for the U.S. Department of Defense. Chapter 10 concludes the report with observations on the implications of the national S&T strategies of the surveyed countries and key recommendations to the U.S. government and the sponsor, the intelligence community.

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2

Methodology

CRITERIA FOR SELECTION OF COUNTRIES

The six countries selected by the sponsor to be included in this review (Japan, Brazil, Russia, India, China, and Singapore, or JBRICS) are a select few from among many countries that have science and technology (S&T) policies of potential interest to the United States. The selection of these particular countries was driven by their variations in country size, level of development, and perceived status as global attractors for S&T innovation. The BRIC (Brazil, Russia, India, and China) countries share several qualities: each has a large land area and is rich in natural resources, and each aims to position its political and economic systems to embrace and benefit from global capitalism. The other two countries, Japan and Singapore, although of contrasting size and notably lacking in natural resources, have made similar economic reforms in the relatively recent past and are widely considered to be models of success. The sponsor hoped that, by looking at these countries together, the Committee on Global Science and Technology Strategies and Their Effect on U.S. National Security would be able to develop a portrait of a country's use of S&T policy to transition from a developing to a developed country and to build a technical capability equal to or surpassing that of the United States. The committee was also requested to identify factors that are found in countries that have created successful environments for innovation.

Although there are many countries whose S&T infrastructures are of interest and could be studied, the limited time allotted for this review and the direction of the sponsor limited the committee's consideration to the six countries listed above.

CRITERIA FOR HIGH-IMPACT/KEY TECHNICAL AREAS

One of the committee's goals was to identify the technology areas for each country that have the greatest potential impact for that country's future and for the United States. Paraphrasing the sponsor, the committee was asked to identify what technologies the six countries are picking as "winners." What appear to be the key technologies on which the countries are focusing for future success? High-impact or key technology areas could be those that have received increased funding or have had rapid or recent improvements in measured indicators. In most cases, the key technology areas were those areas of research and development (R&D) that have been identified by the country for industrial development or for improvements in the national standard of living. However, in some countries the key technology areas were closely tied to military as well as economic competitiveness. The extent to which the committee evaluated such ties was a function of the amount of information in the open literature.

Committee members reviewed each country's S&T plans alongside its observed S&T progress and common indicators to identify the technology areas that could have the greatest impact. These are addressed in the country-specific sections in Chapters 3 through 8. Where possible, the committee tried to assess whether there are better indicators of progress for each individual country and whether each country has the resources to make significant or economic advances in the identified key technology areas. A consequence of the focus on country-specific S&T strategies, rather than on particular areas of S&T, is that coverage in the report of important S&T developments is uneven across the countries.

METHOD OF INFORMATION GATHERING AND EVALUATION

Information was gathered by reading available S&T plans from the countries of interest, listening to experts' presentations on S&T focus areas from the six countries and the United States, and reading other publicly available documents related to the S&T enterprises of the six countries. The committee reviewed rankings, indices, and trends, compiled by other organizations, of items such as patents filed, journal articles published, degrees earned in S&T fields, and funding devoted to research and infrastructure. The committee also reviewed the countries' stated S&T policies, as published in their S&T plans, and S&T spending, when possible. In all cases, funding numbers primarily reflected nonmilitary R&D spending. References are included in the applicable country sections.

The committee focused not only on gathering information, but also on assessing and interpreting the information to how S&T are being developed in other countries and what existing or emerging technologies may pose threats to U.S. security. In order to evaluate the information collected, the committee members relied on their own expertise, experience, personal conversations with experts, and judgment.

One evaluation method was to compare knowledge of a country's S&T plans with information regarding its S&T spending. Measurements of investment in R&D as a percentage of gross domestic product (GDP) can indicate the level of national commitment to S&T development. If the spending for an area is not sufficient to support stable R&D (or progress in that area), then that area may actually be a low priority for that country, even if the policy states otherwise. Although useful, such measures offer an incomplete portrait of available resources; they do not reflect the cost differences between local economies, the impact of technology transfer, or the level of innovation in a given country. An effort was made to identify indicators that capture the major S&T-related trends in each country. Commonly used indicators include metrics such as patents, publications, degrees, and spending. However, interpreting these data in the context of a country's unique and evolving circumstances presents a considerable challenge. Traditional academic and economic measures may not be reliable in some cases because a country's standards or its level of involvement in the global economy or the Western academic establishment may differ. For example, academic advancement in China is linked to the number of papers published, incentivizing scientists to produce a large number of lower quality papers that are not necessarily indicative of more (or high-quality) research. One potential solution to this problem is to focus on communities of researchers as demonstrated by co-authorship rather than on the number of individual papers (Klavans and Boyack, 2009).

The World Bank has developed a benchmarking tool called the Knowledge Assessment Methodology (KAM) to help countries identify challenges and opportunities. The KAM is used to rate countries on 83 variables that have been identified as necessary elements of a functioning knowledge economy, ranking each on a scale from 1 (weakest) to 10 (strongest). Figure 2-1 shows the KAM innovation scorecards for the JBRICS countries on several traditionally cited indicators and compares them with that of the United States.

Economic measures are designed to measure patterns in output of goods from material resources. They do not translate well to measuring innovation, which is not easily quantifiable. Unlike in manufacturing, health policy, or education policy, where records can be collected and analyzed, there are no reliable data on the factors that produce innovation or encourage its adoption. Additionally, research on the impacts of organizational structure and decisionmaking is very limited. R&D investment, often used to predict industry output, may be an unreliable indicator—an increase in R&D spending does not always increase output or improve other indicators. For example, between 1992 and 1995, a series of R&D-focused recovery packages in Japan failed to reverse a decline in industrial R&D, due to policies that discouraged innovation and university-industry collaborations (OECD, 2009). Sweden, too, has seen little growth in recent years despite population growth and heavy investment in R&D (Lane, 2009).

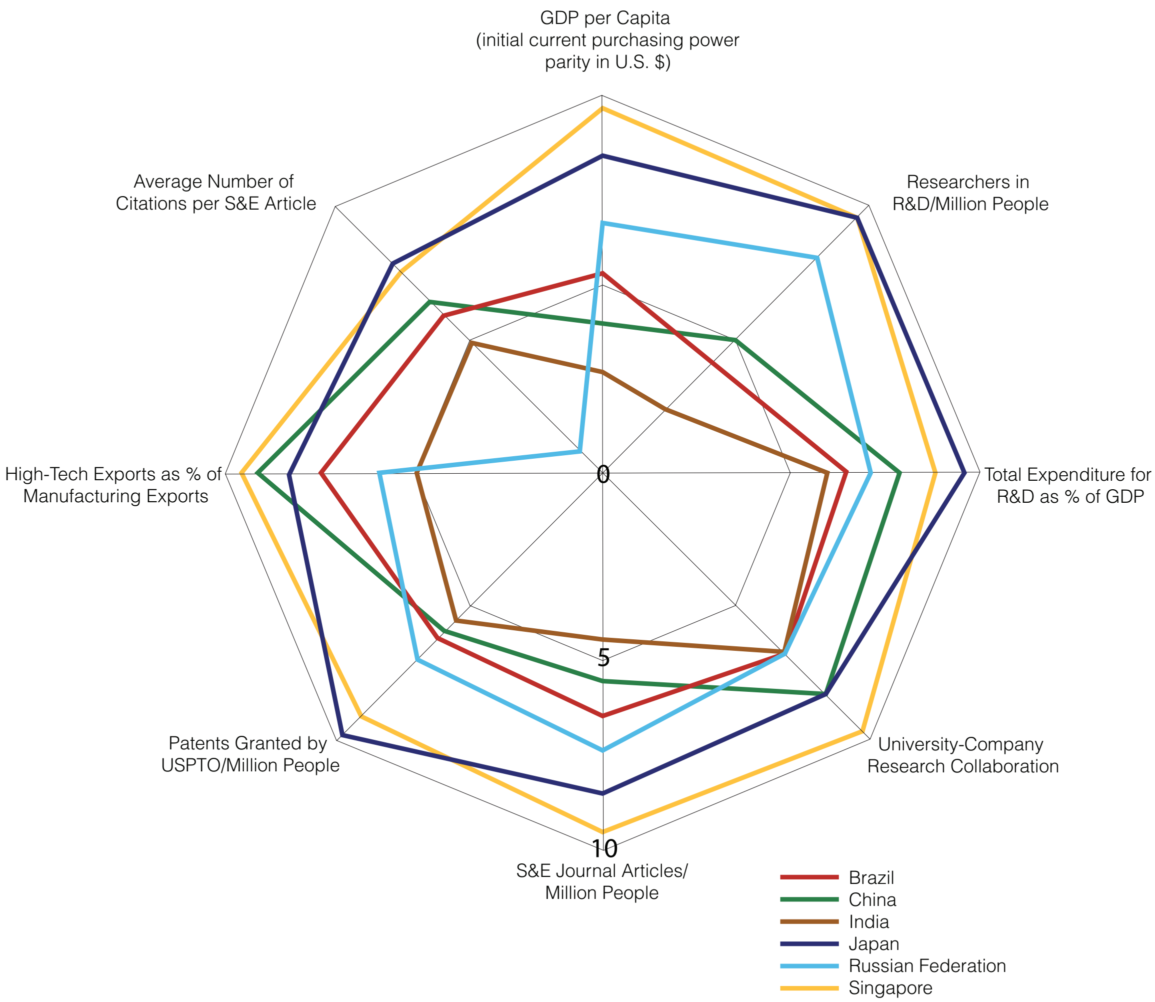

FIGURE 2-1 Comparison of supply and output indicators in JBRICS countries using Knowledge Assessment Methodology.
SOURCE: World Bank. 2009. Knowledge for Development (K4D) Website: Custom Scorecards (KAM 2009). Tool available at http://info.worldbank.org/etools/kam2/KAM_page3.asp?default=1. Last accessed June 14, 2010.

A constellation of cultural, economic, and policy factors must be considered when evaluating the capability of a country in S&T innovation.

In its review, the committee attempted to identify nation-specific indicators that should be used alongside the more globally relevant observables discussed above (e.g., patents, publications, degrees awarded, and S&T budgets) to better monitor, track, and quantify S&T development in other countries and the United States in the future. These nation-specific indicators are discussed in the individual country chapters and summarized in Chapter 9.

RESEARCH TIMEFRAME

The Committee on Global Science and Technology Strategies and Their Effect on U.S. National Security (see Appendix A) started research for the report at its first meeting in November 2009 and completed research in March 2010. During the first three meetings, committee members received briefings and discussed the report structure and approach. Writing and research were primarily performed outside the meetings, and the final meeting was devoted to preparing the first version of the report for review. See Appendix B for a full listing of speakers and briefings.

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3

Brazil

Brazil is the economic leader of the South American countries, with a strong financial and industrial base and substantial natural resource wealth. It regards S&T development as a central and critical element for strengthening national security and reaching its goal of becoming a world economic power while improving social equality. Brazil is currently energy independent and is supporting its development through taxation rather than debt issuance, but government investment in S&T infrastructure is currently a relatively small percentage of GDP, and its industry has been slow to engage in basic research, support research in universities, and employ S&T personnel with advanced degrees. Its challenges in S&T stem from a growing but insufficient number of S&T qualified personnel, limited interest in S&T among university students, relatively little engagement between industry and universities, and a business culture that lacks enthusiasm for the highly valued innovation/commercialization cycle of leading S&T countries. Current strengths lie in the energy sector (nuclear, oil, and biofuels) and the agricultural sector (food production and export). Energy leadership is likely to continue. Major military activities, which are supported by communication and space initiatives, are the surveillance and protection of the country's border and natural resources.

INTRODUCTION

Brazil holds a unique position in the world today—it is a rapidly advancing member of the group of so-called BRIC emerging countries, but it is the only one without nuclear weapons (Wilson and Purushothaman, 2003). Like the United States, it is a young country and therefore does not have millennia of cultural history as do India and China. Brazil's leaders intend to fully position the country as a world economic power and have specifically chosen to develop its S&T capabilities as a pathway to economic health and success. The recent discovery and drilling for oil off the coast of Brazil has provided both energy independence and a major boost to gross national product and S&T spending. Most of Brazil's S&T efforts are directed toward economic expansion and commercialization, with improvements in military capabilities and effectiveness representing only one component of the plans to support the economic health and integration as a global leader of the country.

With nearly 200 million inhabitants, Brazil is the fifth most populated country in the world. Its population is relatively young: 49 percent is under the age of 29 years, and the median age is 28.6 years. Brazil also ranks fifth globally in terms of land area. Nevertheless, it ranks only tenth globally in terms of gross domestic product (GDP) (CIA, 2009).

Brazil experienced instability as it transitioned from a colony of Portugal to a monarchy and finally to a federal republic of 26 states. However, the country has enjoyed considerable political stability within recent years. President Lula da Silva has followed a path of fiscal prudence during his tenure, which has contributed to Brazil's recent rapid economic growth.

Brazil is considered by many in its S&T community to be experiencing a golden moment for development of its S&T environment. Within South America, Brazil is the S&T leader and has one of the most advanced industrial sectors. It is a global leader in agricultural research, deep-sea oil production, and remote sensing. Additionally, its economy benefits from a strong manufacturing base supported by a wealth of indigenous resources and commodities. Brazil's competitive assets include an abundance of natural resources, an extensive and growing domestic commercial market, a well-developed financial market, and a diversified and sophisticated business sector. However, macroeconomic stability, efficiency of goods and labor markets, and the institutional environment continue to be ranked poorly.

Brazil faces a host of social problems, but a growing sense of optimism and a national commitment to development appear to be empowering a substantial segment of the population. Education, particularly in the sciences and engineering, is seen as an opportunity for personal advancement as well as a way to contribute to a positive national movement. However, Brazil's youth have not gravitated to S&T education in substantial numbers to date (Pacheco, 2010). With its optimism and its base of natural and financial resources, Brazil is building an S&T innovation environment that, although not yet time proven, is effectively advancing the country on the global stage.

NET ASSESSMENT OF S&T INVESTMENT STRATEGY

Brazil's primary objective is to gain and hold a position as one of the world's leading economic powers. It is recognized that this objective can only be realized in the long term by also becoming one of the world's leaders in science and technology. Much of the country's current economic strength is a result of its well-established and diverse industrial base and its endowment of natural resources including minerals, hydropower, and hydrocarbons. However, Brazil is lagging in S&T indicators such as global percentage of scientific publications, patents, and percentage of GDP invested in R&D, reflecting a lack of commitment to innovation on the part of industry. It is also recognized that the country must leverage more than its natural resources to achieve economic leadership and security. Key focus areas for S&T investment are energy, defense, development of natural resources (including agriculture), strengthening of industrial innovation, and collaboration between universities and industry.

Analyst expectations are for government programs and initiatives to pay off in the medium term. Some progress is occurring already, as multinationals are attracted to Brazil's inexpensive yet effective engineering workforce. For example, the agribusiness giants Monsanto and Pioneer Hi-Bred International, Inc. have major branches and Ford Motor Company is establishing an important engineering facility in Brazil. The country is beginning to overtake Germany, Italy, and the United States as a destination for multinationals looking to establish S&T facilities.

The government of Brazil began to attend to the issues of S&T competitiveness about two decades ago, and it recently initiated a well-focused effort in the 2007-2010 Action Plan on Science, Technology and Innovation for National Development (PACTI). This plan specifically addresses key S&T deficiencies, including the lack of industry investment in S&T, lack of scientists and engineers employed by industry, limited commercialization of knowledge, and limited expertise in key technology areas. The PACTI's four priorities are (1) expansion and consolidation of the national S&T innovation enterprise, (2) promotion of technology innovation in companies, (3) R&D in strategic areas, and (4) S&T for social development. Furthermore, the PACTI targets the following strategic areas of research (MCT, 2007):

- Information and communication technologies
- Health supplies
- Biofuels
- Electrical power, hydrogen, and renewable energy
- Oil, gas, and coal
- Agribusiness

- Biodiversity and natural resources
- The Amazon and the semi-arid region
- Weather and climate change
- Space program
- Nuclear program
- National defense and public safety (Ministry of Science and Technology, Brazil (MCT), 2007)

The PACTI goals include an increase in national spending on research, development, and innovation (RD&I) from 1.02 percent of GDP in 2006 to 1.5 percent of GDP in 2010, an increase in private investment in RD&I from 0.51 percent of GDP in 2006 to 0.65 percent of GDP in 2010, substantial increases in scholarships for researchers, and the creation of new technology centers (Erawatch, 2010).

This ambitious plan includes some internationally sensitive areas, such as technologies for launching rockets and satellites and enriching uranium, as well as national control of the biodiversity of the Amazon. As part of a separate initiative, President Lula da Silva, blaming industrialized nations for the "unsustainable patterns of production and consumption," announced massive new protections for the Amazon during a 2006 United Nations biodiversity meeting (SCBD, 2006). In the plan, 84,000 square miles of the Amazon rain forest (about the size of Kansas) will be declared a protected zone over the next three years. Efficient administration of these natural resources will be advantageous for Brazil, but balancing economic growth and environmental preservation will be a challenge.

With some exceptions, most of the financial support for S&T is not directed toward military applications. Negotiations are currently underway with France to purchase military aircraft and to engage in a major technology transfer, reflecting strong ties between Brazil and France. However, in the most recent call for applications for federal R&D grants, no military-related projects were presented. Instead, interest centered on environmental technologies (advanced water treatment, for example), an area in which Brazil is gaining prominence. Brazil is also placing renewed emphasis on the security of its borders, primarily to protect its natural resources. The United States and other developed nations will soon have to negotiate with the Brazilian government to access these critical resources. Military technologies such as space and sensor applications (cybernetics) and specialized vehicles (naval and multipurpose) are considered critical for boundary protection and monitoring.

The National Council for Scientific and Technological Development (CNPq) created the National Institutes of Science and Technology (abbreviated as INCT, for Instituto Nacional de Ciência e Tecnologia), which are located in 16 different states in Brazil and function as a national S&T network. The institutes were funded with approximately $330 million in investments, a record amount for research funding in Brazil (Erawatch, 2010). The government spends a relatively small percentage of GDP on S&T plans; however, its strategy is to work within its financial means rather than to go into debt.

A key deficiency in Brazil's S&T enterprise, recognized by its government, is a multi-component gap between academia and industry. Enhancement of academic programs and support for graduate education have not translated into integration of either ideas or graduates into industry. Because industry invests little in R&D, either in house or in academia, Brazil must depend on other countries for the importation of innovation. The 2007-2010 PACTI attempts to address these key deficiencies, but it is not clear that the government programs will foster self-sustaining investment policies by industry.

In an effort to reduce the nation's dependence on foreign innovation, the Brazilian government has created more than 30 incentives for businesses to invest in innovation. Although only about 70 companies utilized these programs when they were first introduced in 2006, the number increased to 500 by 2008, and further increases are anticipated. The incentives fall into three main categories: support for technical expertise, research grants to nonprofit facilities, and funding provided for commercial development in strategic areas (such as light aircraft, conventional energy sources, renewable energy, and nanotechnology). Approximately $3 billion in nonreimbursable funds and tax credits has been provided over a four-year period (Erawatch, 2010).

Another area in which Brazil has made recent investments in order to reduce its dependence on imported innovation is medical biotechnology. Both private and government-controlled entities are engaged in meeting the large demand for health products for Brazil's nearly 200 million people, many of whom live in poverty. Recent industry involvement in public-sector efforts to accelerate health product innovation and provision has resulted in significant developments, but obstacles such as the limited investment in original R&D, the government's view of health-related costs as expenditures rather than investments, and the reluctance to promote competitively priced pharmaceuticals in international markets continue to discourage investment in biotechnology innovation (Rezaie et al., 2008). Nevertheless, Brazil's ability to respond effectively to epidemics and other threats has improved greatly as a result of these and other initiatives in the biological sciences.

Brazil suffers from a shortage of engineers and scientists. There are many scientists in the country, but most are employed within the university system. In response to this problem, Brazil is attempting to strengthen ties between industry and academia to engage professors directly in industrial development. The government currently runs a program that pays half the salaries of Ph.D. researchers for their first three years of employment in industry. The salaries are competitive, ranging from $6,000 to $7,000 per month for half time (Erawatch, 2010; Grynszpan, 2010). Although efforts to understand and enhance internal capabilities are underway, there are no organized efforts to attract experts from other countries. In the medium term, however, there may be attempts to accelerate development of specific technology areas through the employment of outside experts.[1]

Although a full evaluation of the success of the 2007-2010 PACTI is not available at this time, it is reported that a significant quantity of government grants, loans, scholarships, salary support, and other instruments of the plan have been strategically placed. The key challenge in this effort is for the country to make the transition from government-supported efforts to self-supporting and sustainable activity by industry.

PROJECTED ADVANCES IN S&T PROFICIENCY

The current S&T strategic plan for 2007-2010 is nearing completion, and, as mentioned above, there is no assessment yet as to its effectiveness. The committee found no plan extending beyond 2010, and the nature of future planning will likely be affected by general elections for the country's leadership, now slated for October 2010. Current goals target the major deficiencies, and it is reasonable to assume that future areas of focus will be consistent with previous ones. It is not clear how quickly Brazil can make the necessary transition to industry-supported S&T research and investment. Industry seems to lack the motivation and cultural framework to invest in R&D.

Electricity consumption in Brazil has grown substantially since 1990 and is projected to continue to grow, making domestic energy production a key security issue. Brazil has already met its previous goal of attaining net-zero oil imports; down from importing 70 percent in the mid-1980s. Current estimated oil reserves of 30-80 billion barrels place Brazil within the top 10 countries in reserve capacity. Nearly three-quarters of the country's electrical energy is produced by hydropower, and plant-derived ethanol accounts for more than 50 percent of its fuel usage. Brazil's energy reserves, tapped by robust offshore drilling activities, also feed into its national strategies for economic, energy, and technological independence, in turn positioning the country for greater development in S&T infrastructure and for strong relationships with other countries.

Brazil's academic research base is well developed and able to propel the nation to a high level of technological proficiency. In spite of this, a current shortfall in talent, due in part to the emigration of many members of the urban educated class during Brazil's economic crises in the 1980s (Antico, 1998), lays doubt as to the country's ability to gain leadership positions in some of the new research areas (e.g., nanotechnology) introduced in recent plans. Nuclear and space programs are also strong, although Brazil has yet to launch its own spacecraft.

Some international companies are increasing their R&D investments in Brazil, but it is less clear how long it will take for indigenous companies to change their culture and place emphasis on innovation and research. Significant improvement of innovation and research can be expected within a five-year timeframe.

S&T INVESTMENTS OF INTEREST

To achieve its larger goal of economic leadership, Brazil is striving for total energy independence and for control and preservation of its natural resources. Brazil is reinforcing its role as a global leader in agricultural

[1]Personal communication from Valter Pieracciani, CEO and managing partner of Pieracciani, São Paulo, Brazil, to committee member Paul Gailey on January 6, 2010. See http://www.pieracciani.com/br/eng/home.asp for more information.

production of both fuel and food for international export. Finally, Brazil has made considerable investments in satellite and space exploration technology, and it is developing military applications for many of its major S&T innovations, particularly for use in overcoming domestic security issues.

Energy

Hydrocarbon-rich Brazil both prioritizes and attracts investment in technological R&D into the exploration, production, and transport of oil and natural gas. In particular, Brazil has invested heavily in and is recognized as a world leader in deep-water and ultra deep-water drilling. Brazil announced in early 2008 the discovery of two oil fields off the coast of Rio de Janeiro, which are estimated to hold between 30 billion and 80 billion barrels. Output from both existing and new fields could make Brazil a significant oil exporter by 2015. However, current production from drilling is outpacing refining capacity, and some crude oil must still be traded for refined oil. Brazil aims to increase its refining capacity from 1.9 million barrels of crude oil per day (BPD) to 3 million BPD by 2020 (U.S. DOE, 2009). A research program for the production and clean use of coal is also in development.

Brazil's initiatives in electrical power, hydrogen, and renewable energy sources include developing new technologies for the generation, transmission, distribution, and use of electrical energy; consolidating programs for a hydrogen economy; and implementing plans for renewable energies. Hydroelectric, wind, solar, biogas, and biomass hold the most potential for development.

Brazil leads the world in biofuel exports, and, after three decades of refining methods to produce ethanol from sugarcane, it provides 42 percent of global ethanol. The leftover fiber (bagasse) is also used in the processing of heat and power, yielding a very high rate of energy output per input. Brazil's leadership role in renewable energy, biofuels, and other environmental activities have helped position it as a major player in setting global environmental policies.

In 1975 the government adopted a policy of nuclear self-sufficiency and signed an agreement with West Germany for the supply of eight 1,300-megawatt (MWe) nuclear units over 15 years. Two were to be built immediately with equipment from Siemens-KWU, and six were to be built with 90 percent Brazilian content under a technology transfer agreement. Brazil's two commercial nuclear power reactors began operations in 1982, and a third is under construction at the time of this writing. Construction and operation of nuclear power plants is conducted by the state-owned company Eletronuclear, which hopes to add up to 8 gigawatts (GWe) of new nuclear capacity by 2030. The government hopes to have 60 GWe of nuclear capacity installed by 2060 (IAEA, 2004; WNA, 2009).

Biological Resources

In recognition of its unique and rich land area, which includes the Amazon basin, Brazil is focusing significant effort on maintaining its biodiversity and other natural resources. It emphasizes mechanisms for protecting biodiversity, environmental protection, managing the knowledge base for biodiversity, and developing and refining products. Despite these intentions, the country still suffers a steady loss of rain forest in the Amazon basin, a problem it has not yet been able to solve as agriculture expands into the region. Brazil is also consolidating a research program in Antarctica.

Although Brazil is already a global leader in agribusiness, it seeks to increase its technical knowledge base and to maintain and increase its competitive capacity by further developing dietary and nutritional safety initiatives such as quality foods and functional foods, increasing agricultural automation, supporting R&D for innovative production systems, and increasing international links for agribusiness RD&I.

Space

Brazil entered the space age in 1973 with the launching of the SONDA II rocket, part of a program to determine electron density in the low ionosphere, which is a question of practical importance for aircraft navigation (Filho, 2008). Brazil's space program is active and well supported. Its goals are to develop space technologies that benefit Brazilians, such as those that provide answers about environment and global climate change; enhance surveillance of national territory, the study of natural resources, and air traffic control; and establish a space infrastructure including a launch center.

Military Science and Technology Plans[2]

The overarching theme of the Brazilian military strategy is to focus on capacities rather than on enemies. Plans for military growth and development are therefore closely aligned with the general plans for science, technology, and innovation (ST&I) discussed above. Brazil strives to further its security and economic well-being by stimulating and supporting the integration of Brazil with other South American countries. To promote these objectives, the military focuses on advancing capabilities and leadership in nuclear technology, the space sector, and cybernetics.

The military plans to utilize nuclear energy to power submarines that will be deployed to protect the oil platforms along the country's coastlines. Furthermore, the military considers nuclear energy to be a backup source of energy to existing hydroelectric power, which makes it critical to the country's energy independence and security. Plans call for the development of technologies to locate and mine uranium and to employ nuclear power for various applications (IAEA, 2004).

Monitoring Brazil's vast territory is best accomplished through satellite technology. The military expects to develop the capability to design, construct, and launch satellites into low and high and geostationary orbits. Priorities in this area include the development of launch vehicles, inertial guidance systems, remote sensing instrumentation, geographical mapping systems, and control systems. Efforts are also underway to address the special needs of the military in protecting this vast territory, including the development of multi-purpose ships that can operate in rivers or oceans and have platforms for helicopter operations.

Brazil's leaders consider cybernetic technology to be critical to the support of both military and civilian communications. Brazil aims to facilitate intercommunication between defense forces and with space vehicles, and to protect and defend the resources within the vast Brazilian territory through advanced methods of monitoring and information gathering.

Military planners in Brazil recognize the importance of supporting both basic research and applied, technology-oriented research, which may not yield economic benefits in the near to medium term. The military intends to work with industry to develop productive capacity for defense materials.

NATION-SPECIFIC INDICATORS OF S&T ADVANCEMENT

Traditional S&T indicators depict Brazil as a country with a growing economy but low levels of innovation (see Figure 2-1 for a comparison of Brazil's performance on common S&T indicators to those of the other JBRICS countries). Brazil's global standing is rapidly improving according to overall S&T indicators, but its standing is still relatively minor according to traditional indicators such as percentage of world scientific publications (2.1 percent), percentage of GDP invested in RD&I (1.2 percent), percentage of GDP invested in RD&I by industry (0.51 percent), and world patents (0.2 percent). In order to gauge the speed and direction of Brazil's S&T growth, indicators should be chosen that accurately monitor changes in the following areas:

- Industry involvement in the national S&T enterprise
- Development of capabilities in satellite launch and operation
- Availability of industry jobs for Ph.D. graduates
- Government and industry financing for research
- Integration and collaboration with other South American countries

[2]Information obtained from December 18, 2008, memo to the President of the Republic of Brazil from Nelson A. Jobim, Minister of State for Defense, and Roberto Mangabeira Unger, Minister of State of the Strategic Affairs Secretariat of the Presidency. Available at https://www.defesa.gov.br/eventos_temporarios/2008/estrat_nac_defesa/estrategia_defesa_nacional_portugues.pdf. Last accessed February 20, 2010.

- Academic publications and patents

Industry Involvement in S&T

Brazil's comparatively low innovation rate is due to a variety of interwoven factors, from the high cost and risky nature of investing in innovation in Brazil to the lack of highly qualified human resources. In addition, compared to the other JBRICS countries, Brazil is a latecomer to the S&TI realm. Over the past decade, however, Brazil has reprioritized ST&I in the public policy agenda. Dramatic changes have been made in the ST&I enterprise, including the establishment of the Science and Technology Sectoral Funds in 1999, which are tools to provide secure ST&I funding using resources from select productive sectors. New laws calling for the convergence of technological and industrial policies and for the enhancement of ties between industry and universities in carrying out R&D have also helped to shape Brazil's efforts to make innovation a policy priority. At the forefront of this reprioritization is the Financiadora de Estudos e Projetos (Financier of Studies and Projects), or FINEP, a public firm under the Brazilian Ministry of Science and Technology established in 1967 to encourage and mobilize ST&I research in businesses, universities, technological institutes, research centers, and other public or private institutions. FINEP provides grants for innovative projects through the National Fund for Science and Technology, and it serves as a bank, issuing loans to firms investing in innovation.

Satellite Capabilities

Brazilian space researchers and the air force, with Russian expertise, are developing a satellite transport rocket. Brazil hopes to launch the rocket in 2011, confirming its ambition to join China and Russia as a top emerging economy with its own space program. The Brazilian Space Agency already has conducted successful tests of one of the rocket's engines. This success underscores the agency's determination to fulfill its mission, despite a 2003 accident that killed 21 Brazilian technicians and engineers and destroyed the launch structure.

Higher Education and Jobs

Brazil's academic base has grown significantly during the past 10 years, as the number of master's and Ph.D. degrees has grown about 12 percent per year (MCT, 2007). In 2007, 10,000 doctoral degrees were awarded, and the nation hoped to reach 16,000 by 2010 (MCT, 2007). However, this number is considered insufficient for the country's developmental needs, and consequently more emphasis is being placed on strategic sectors such as engineering and other areas developing future trends. The problem is exacerbated by an apparent lack of industry jobs for Ph.D.s within the country. Although there were an estimated 200,000 researchers in Brazil in 2008, fewer than 10 percent of them were employed by industry (Pacheco, 2010). This number can be compared to the nearly 800,000 scientists employed by industry in the United States (Pacheco, 2010). An increase in private-sector employment of researchers would indicate an improved environment for domestic innovation and would bode well for continued growth in the number of students pursuing degrees in S&T fields.

Government and Industry R&D Expenditures

Government R&D expenditures in 1994 amounted to $664 million. Furthermore, Brazilian businesses invest only a small percentage of GDP in R&D activities (0.51 percent in 2005)—less than their counterparts in more advanced countries. This lackluster performance is reflected in the World Economic Forum's index of world competitiveness for 2009/2010, in which Brazil was ranked 56th out of 125 countries, ahead of Russia but behind India (49th) and China (29th) (Sala-i-Martin and the World Economic Forum, 2009). In spite of this, Brazil has made substantial economic gains and is expected to benefit more from the current global recession than any other country surveyed in this report (EC, 2008).

Regional S&T Integration

In 1985, Argentina, Brazil, Paraguay, Uruguay, and Venezuela created a regional trade pact, Mercosur, of which five other Latin American countries (Bolivia, Chile, Colombia, Ecuador, and Peru) are associate members. Closer technological cooperation and a common desire to boost innovation were central to this bid for regional integration. These 10 neighbors have created cooperative programs for ST&I, promoting links between research institutions and private companies. A key issue arising from discussions about innovation is how to better transfer knowledge between universities and research centers on the one hand, and private companies—in which R&D activities are still limited in Latin America—on the other. The concern is that most of the knowledge produced by research institutions stays on the shelf and has little impact on society. Of all the Latin American nations, Brazil has done the most to address this concern through its forward-thinking policies to promote innovation.

Academic Publications and Patents

In terms of academic outcomes, in 2008 Brazil ranked 13th in the world in numbers of published scientific works. From 1981 to 2006 the number of articles published in international journals increased by 8.9 percent per year (compared to a global increase of 2 percent per year). The accumulated increase in publications by Brazilian scientists was approximately 232 percent, compared to the world average of 73 percent. In 2005, Brazil ranked 13th in nations applying for patents, compared to China (3rd) and India (11th). That same year, the number of patents originating in Brazil decreased by 13.8 percent from the previous year, while those in China increased by 32.9 percent and those in India increased by 1.3 percent (Embassy of Brazil, 2009).

FINDINGS AND RECOMMENDATIONS

Brazil holds an important position globally. In addition to the fact that most of the world's rain forests lie within its borders and it plays a leadership role in global ecological activities, Brazil is richly endowed with natural resources, including both hydrocarbons and renewable energy sources. Growing overall populations and middle classes in some of the world's most populated countries are resulting in increasing demand and pressure on resources such as energy, water, food, and minerals. Brazil is succeeding in using S&T to leverage its natural resources to help supply these needs while improving its own economic health.

Finding 3-1. Brazil's current and likely continuing energy independence places it in a unique and important global position, less easily influenced than other countries by the United States. It is therefore important that the United States foster a productive relationship with Brazil, which is currently the leader and key to South America.

Brazil's current wealth and success result in part from its endowment of natural resources, strong industrial sector, and prudent fiscal policies. However, the country recognizes that continued success depends strongly on the assumption by industry of a larger role in R&D and the translation of academic knowledge to wealth. Brazil's future position on the global stage depends on this step.

Recommendation 3-1. The United States should accelerate strengthening a productive relationship with Brazil, which is the leader and key to South American S&T. To this end, the United States should consider working with Brazil in critical areas such as building its national S&T innovation environment.

Finding 3-2. Brazil is in the process of securing its borders against unauthorized use and study of its bio-resources, which represent a wealth of biological, agricultural, pharmaceutical, and medical applications.

Recommendation 3-2. The United States should maintain a cooperative relationship with Brazil that provides for appropriate U.S. access to Brazil's resources.

Finding 3-3. Brazil's leadership roles in deep-water drilling, biofuels, and other biotechnology-related and agricultural enterprises are likely to increase in importance in the coming years. In an increasingly multi-polar world, Brazil represents an important political partner for the United States. Its military is oriented toward non-aggressive goals, and it is becoming a prominent member of the global community as its importance in the Western Hemisphere increases. Other developed countries are increasing, and will likely continue to increase, their assistance to Brazil in the near term.

Recommendation 3-3. Because Brazil is a global leader in technology fields that are important to U.S. security and energy interests and because it engages with Russia, China, and Iran, among other countries, the United States should monitor and evaluate Brazil's international partnerships.

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4

China

China's goals for science and technology (S&T) development are continued economic growth to promote prosperity and the military, movement toward an innovation-driven society that has thus far been elusive, attention to significant and growing environmental degradation, a focus on dual-use technologies, and global recognition of its return to the world prominence that it held more than a century ago. Chinese leadership uses its authority to align national culture with the needs for economic growth in S&T. China relies on global trade and acquiring innovation from abroad and uses its domestic market to attract multinational corporations. A high rate of growth in its gross domestic product (GDP) enables its priority investment in S&T infrastructure. Areas of S&T focus are many, although significant impacts are expected in information technology (IT), energy, and biotechnology.

China's trajectory depends on the resolution of conflicts that are currently in play: desire to establish internationally competitive, national technology standards and various other efforts that involve wresting ever-more advanced technology transfers from foreign investors in order to aid creation of a more indigenous innovative society. The latter efforts will increasingly shape the type and amount of foreign investment in China. The conflict between open access to information and the national need to enforce political stability will also need to be addressed.

The United States should endeavor to ensure a collaborative yet strategically competitive relationship with China to benefit from Chinese resources and to jointly promote global stability while addressing issues of open access and technology transfer.

INTRODUCTION

Since the initiation of Deng Xiaoping's market-opening reforms in the early 1980s, China has become the world's largest exporter, the third-largest economy in terms of GDP (having recently surpassed Germany and expected to soon surpass Japan in second place), and is home to more researchers than any other country. Underlying this dramatic progress has been an economic development strategy characterized by exploitation of the global marketplace for investment, technologies, and scientific knowledge. These efforts have coincided with the emergence of an information technology-driven boom in globalization, further accelerating progress and modernization in China's economy and S&T community. As a result, China is a world economic leader and may be on the cusp of becoming a world-class S&T competitor.

Projections of China's S&T future have recently become more optimistic, based on the country's recent improvement in S&T indicators. China's promise is magnified by its sheer size and the persistent strength of its economy, even in the face of an extended global economic recession. Nevertheless, China must contend with significant challenges, which include currency inflation, outsized global trade surpluses, corruption, high unemployment and income disparities, projected resource constraints, and sustainable development challenges, as well as the potential for a decline in China's economic growth rate. China's recent advances in S&T proficiency satisfy only a fraction of the broader national need for development. A critical aspect of China's continuing economic and S&T transformation is the phased-in promotion of economic development and modernization across China's vast and disparate territory, as envisioned in China's "Go West" strategy. If successful, this strategy has the potential to support an economic, industrial, and S&T expansion for decades to come (The Economist, 2010). Today, much of China's scientific community remains set apart from the market-driven dynamic that characterizes the country's coastal economic zones and foreign-invested enterprises. This and other systemic challenges lead some observers to be more skeptical about the sustainability of China's fast-paced expansion in both economic and S&T capabilities.

China is an authoritarian state with a centrally planned economy, enabling it to quickly enact S&T policies. But such systems are vulnerable to problems such as excessive waste, redundancy, corruption, and difficulty in altering or reversing course mid-plan. In recognition of these limitations, Chinese state plans have evolved from strict, quantitatively driven mandates to "guidelines" and encourage more collaborative approaches to decision making. For example, when developing its medium- and long-term plan (MLTP), China brought in an array of domestic and international experts to assist in determining what and how to prioritize future S&T development.

In China, the pursuit of scientific and technological endeavors is considered a worthy ambition, as well as the answer to societal and environmental problems. Scientists, engineers, academics, and increasingly entrepreneurs are valued in Chinese society and economy, and China's present leaders are considered to be technocrats. Recent surveys suggest strong popular support among Chinese citizens for scientific pursuits, with 74 percent of Chinese responding positively to the idea that "even if it brings no immediate benefits, scientific research which adds to knowledge should be supported by government" (NSB, 2010, p. 7-30). Promoting widespread scientific literacy is also a key priority. In 2006, China implemented an "Action Plan to Increase the Population's Understanding of Science." This plan, the first of its kind in modern China, is expected to be implemented through 2020 (Chen et al., 2009).

Although endowed with a broad enthusiasm for science, China remains a largely risk-averse, collective-oriented culture. This has hampered some efforts at adopting Western-style entrepreneurism and innovation, and in response China's government has instituted policies and programs that promote more risk-oriented financial and organizational ventures. Other initiatives, such as the Chinese Academy of Sciences' Knowledge Innovation Program, promote high-profile or interdisciplinary innovation. What these approaches will yield and how Chinese innovation will look compared to Western innovation is unclear, both to Western analysts and China's own leaders. China's adaptability and willingness to learn from other nations, however, will be essential to its S&T advancement. China's "Go Abroad" policy (to enhance domestic firms' brand, R&D assets, and technology access) was implemented to overcome these technology gaps and to enhance China's continued, long-term access to global investment, technology, and know-how.

China's economic growth and subsequent investment in S&T is transforming it into a regional and global hub for not only industrial production but increasingly also for industrial R&D, and to a lesser extent, basic research. As a partner with many of the world's leading economies and global corporations, China appears to be finding it easier to catch up to the forerunners and is doing so at an unprecedented pace. The question remains whether and how China will attain S&T leadership.

NET ASSESSMENT OF S&T INVESTMENT STRATEGY

China's S&T investment strategy is ambitious and well-financed but highly dependent on foreign inputs and investments. Many of its stated S&T and modernization goals will be unachievable without continued access to and exploitation of the global marketplace for several more decades. China plays a critical role in low- and select high-tech industry production and logistics chains, but it cannot (yet) replicate these processes domestically. As such, China has become an increasingly critical node in U.S. commercial and, in some cases, defense production as well as in the research and development (R&D) efforts of multinational corporations. Foreign-invested R&D in China constitutes an explicit and critical component of China's long-term S&T and industrial development strategies. Currently, China is host to more than 1,200 foreign-invested R&D centers, which represents 3 percent of developed countries' global R&D investments (Simon, 2010). Yet, although foreign R&D investments have increased and, in some cases, have focused on more advanced forms of R&D (i.e., on basic and applied research rather than on technology development and product design), there has also been a transition from Chinese-foreign joint ventures to wholly foreign-owned enterprises, which introduces security and intellectual property concerns and thereby limits the prospects of technology spillover. Subsequently, innovative connections between foreign firms and China's national innovation system have strengthened in the industrial sector but remain weak in the government and academic research institutes.[1] It should be noted that this report does not include analysis of the possible national security consequences of U.S. indebtedness to China.

These trends in foreign investment can be explained by an oft-noted concern about China's commitment to the rule of law and, specifically, to intellectual property (IP). China has been slow to enforce a regime that is effective in ensuring that copyrighted, patented, and otherwise protected IP, either domestic or foreign, is preserved. In fact, China's current IP regime is so poorly regarded, and the government's increasingly confrontational stance toward IP is sufficiently worrisome, that very little cutting-edge R&D will be performed by multinational corporations in China. The speed with which this situation is remedied and protections become effectively implemented will help determine the amount and level of foreign partnerships available to Chinese companies.

China is attempting to develop national technology and industry standards, which are intended to promote home-grown technologies that can serve as regional and global standards. To achieve this objective, China often pressures or requires (via regulatory changes) foreign firms to share core technology specifications. For example, China recently enacted an anti-monopoly law that enables it to break what it considered to be "monopolization" of key technologies by multinationals. This law forces companies to adopt the indigenous innovation regime, thus compelling them to transfer proprietary technologies to their Chinese subsidiaries or risk losing access to procurement by state-owned enterprises, which in some sectors comprise the largest part of the domestic market. Such efforts have thus far had mixed, mostly failed, results in the public domain; some companies choose to comply with informal technology transfer mandates or market pressures in an attempt to capture greater market share. Efforts to develop and enforce China-origin standards are explicitly promoted in various state plans and are likely to continue.

NATIONAL S&T GOALS

China's long-term national S&T goals are to become a leading economic, industrial, and military power, and in doing so to reclaim China's past scientific and technological glory. For this reason, China seeks to demonstrate its S&T capabilities in internationally competitive S&T sectors. Similarly, in an effort to gain technological and therefore economic self-sufficiency, China aims to increase its domestic technological input to 60 percent of economic growth and to limit its overall dependence on foreign technology to less than 30 percent. These larger milestones will be achieved by way of specific goals and strategies for S&T that are outlined in regular five-year plans (FYPs) and in longer-term plans designed to address emerging trends, challenges, and opportunities. These general plans are supplemented with more detailed, industry- and sector-specific S&T plans and programs. Government officials are presently implementing the 11th FYP alongside a 14-year MLTP and the Chinese Academy of Sciences' S&T plan for 2050. There is little that is not included in these plans, making prioritization a key consideration in determining where and whether China's S&T goals will be achieved. The current MLTP identifies five strategic priority areas, which are listed below (Li, 2009):

- Development of energy and water resources in conjunction with environmental protection efforts
- Acquisition of core manufacturing and IT technologies

[1]China and foreign universities are rapidly establishing new academic relationships, but whether or not the quality of these relationships is such that they will contribute to Chinese innovation remains to be seen.

- Increase in focus on biotechnology
- Acceleration of space and marine technology development
- Enhancement of basic science and frontier technology research capabilities, with an emphasis on multi-disciplinary research

China's leaders are presently drafting the next FYP, which will take effect formally in early 2011, and they are preparing for the upcoming 18th Party Congress, which will take place in 2012. It is expected that the successors to Chinese President Hu Jintao and Premier Wen Jiabo will be determined at or around this time and that they will steer the country along a relatively similar S&T development path.

PROJECTED ADVANCES IN S&T PROFICIENCY

China's S&T objectives are typically based on traditional indicators of Western S&T progress. According to such indicators, China has made impressive gains in recent years; however, its actual world position in S&T terms remains uncertain. There are several reasons for this ambiguity. First and foremost is that China's own statistics and analytical methodologies remain questionable and, despite many years of international consultation under cooperative arrangements with the Organisation for Economic Co-operation and Development (OECD), National Science Foundation (NSF), and others, are not entirely commensurate with international data sets. Almost all analyses indicate that China has made significant gains in S&T over the past 15 years, but the use of different indicators and measures has resulted in different conclusions about the exact scale, breadth, and rate of China's overall success. For example, the Georgia Tech High Tech Indicators (HTI) survey ranks China's economy as 1st out of a selection of 33 countries, while the Global Competitiveness Index (GCI) survey ranks China's economy as 54th out of 125 countries (Porter et al., 2009). These divergent outcomes illustrate the challenge that remains in assessing more precisely China's current and future innovative capacity. As with many developing countries, traditional S&T indicators do not fully explain or predict China's S&T progress to date and into the future.

In the meantime, China's development plans provide some means of assessing where the nation is headed and how effectively the government's own goals have been achieved over time. The country appears likely to achieve many of its stated S&T goals, although not necessarily within stated timelines, except in those areas that emerge as national security priorities. The government devotes significant (and often costly) resources and effort to achieve these latter goals, particularly as deadlines draw near. Examples of this phenomenon are demonstrated by the "2 bombs, 1 satellite" program of the 1950s-1970s to rapidly develop nuclear, missile, and satellite capabilities and more recently by China's Shenzhou missions and continuing advances in its manned space program (Feiganbaum, 2003; Wu, 2006). Because reform of China's national S&T enterprise is a vital component of its long-term modernization and defense strategy, it seems likely that S&T-related objectives will remain a top priority, barring some unexpected and large-scale disruption.

One possible source of disruption is the volatility of global markets, which, in the short term, could limit the foreign inputs of expertise, investments, and technologies on which Chinese growth depends. Nonetheless, momentum in development and innovation in China is high and is safeguarded in part by a high savings rate and spending ability. China's political stability is another area of concern, but if economic factors and issues related to social and economic inequality can be managed, Chinese S&T will likely continue to advance as it has in the recent past. China's principal challenges will be found in prioritizing S&T objectives, realizing efficiencies and innovative return on investments, and balancing nationalistic goals with the needs to maintain access to foreign S&T inputs and to effectively exploit globalization trends.

China's rate of internal technological invention continues to lag well behind that of the United States and other Western nations, although the country has considerable resources with which to acquire technology for research, which it is indeed doing. For example, there is a national effort underway to build a research network in the field of structural and functional magnetic resonance imaging (MRI), using imported machinery (NRC, 2008). China holds greater near-term promise with regard to translating others' inventions into commercial products. Unanticipated innovations might arise from the convergence of the vast array of S&T capacities currently in development, particularly in prioritized areas, or from the convergence of ideas from multiple fields of study.

S&T INVESTMENTS OF INTEREST

There are numerous areas of S&T investment that could have high impact on China's economic competitiveness, social development, and military capabilities. Prime among these are the areas of information technology; energy and "clean" or "green" technologies; nanotechnology and new materials; and space, satellite, and sensor technologies. Biotechnology is another fast-growing field, representative of the increasing trend of Sino-foreign collaborative R&D efforts. Each of these areas is an identified priority and could lead to unexpected, innovative, or transformative advances. These areas also present dual-use S&T opportunities, which are a focus for the Chinese government and are intended to enhance both economic and military modernization efforts.

In addition to funding R&D in priority fields, the Chinese government is supporting high-level spending on core infrastructure that will have a broader impact on Chinese society and possibly beyond. This includes spending on education, construction of science parks, universities, highways, and other facilities necessary for high-capacity and technologically advanced development across China's territory, as well as on information-sharing networks and databases designed to enhance cross-sector knowledge transfers. These efforts bolster the national emphasis on dual-use technology development, basic sciences, and new S&T fields (e.g., alternative fuels and "green" technology) that offer the potential to transform not only science and industry but also society as a whole.

As discussed in the section on S&T goals, China has identified a long list of strategic S&T priorities. Among the most fundamental, high-impact S&T areas are information technologies, sustainable energy development, and biotechnology.

Information Technology and Communications Sector

China's path toward its long-term objective of becoming a technological superpower has begun with the use of foreign technology that is modified to Chinese domestic standards and contains intellectual property owned by Chinese majority-owned companies or Chinese nationals. Most Chinese high-tech products are copies from other countries; original inventions are rare on the mainland, but China will nevertheless pursue new technologies independently. As noted earlier, the information and communications sector (including computers, telecommunications systems, semiconductors, and associated software and information systems) has been identified as a national priority and occupies a central role in national defense and security strategies. Currently, about 90 percent of Chinese products in this sector are based on foreign technology. Under the rubric of the "863" high-technology plan, the "973" basic research plan, and the Gongguan or "tackle" plan, the following areas will likely be targeted for independent research, because they are perceived to be areas of weakness and obstacles to autonomy in IT and communications:

- **Embedded systems** include embedded hardware (microprocessors, microcontrollers, and signaling processors) and software (operating systems, R&D and design tools, databases). Despite gains in developing logic devices, China is far behind the international leaders in this area (State Council PRC, 2006).
- **Large-scale "informatization" of design** includes engineering software such as model-driven architecture (MDA), electronic design automation (EDA), 3-D computer aided design, and large-scale product data management (PDM).
- **Large-scale control equipment and systems** refer to digital systems that control entire production lines and processes, an area in which China lags despite years of developmental effort.
- **Systems integration** focuses on integrating diverse hardware, software, and equipment into reliably functioning information and communications systems. Despite considerable strides in recent years, China continues to experience difficulty in producing reliable integrated IT systems.
- **Encryption** is considered to be a key element for national security. As part of a broader effort to develop a "national information security support system," China seeks to develop an encryption system for trusted computing based on Chinese algorithms and informed by domestic security requirements (Jiefangjun, 2007).
- **Virtual reality** refers to technologies that synthesize disciplines such as electronics, psychology, control technology, and graphics to create simulations for use in military, industrial, and medical systems, as well as in consumer entertainment products.

- **New materials** refer to nanotechnologies, superconducting materials, photosensitive materials, "smart" materials (combining sensing, control, and execution functions), and other materials used in information hardware and systems.

For the foreseeable future, China's policy in the IT sector will primarily rely upon accessing innovative technologies that are developed outside of China. Where possible, China will gain access to those technologies by entering into international cooperation arrangements or by enticing or coercing leading-edge foreign IT enterprises into technology-sharing arrangements. In other cases, China will use methods that have a coercive dimension. For example, China has just enacted an anti-monopoly law that prohibits the "abuse" of intellectual property rights and that was promulgated, in substantial part, to enable China to break what is seen as "monopolization" of key technologies by multinationals. Adoption of the indigenous innovation regime will compel multinationals to transfer proprietary technologies to their Chinese subsidiaries on legal terms that most will regard as unacceptable—the alternative being the loss of access to procurement by state-owned enterprises, which in some sectors comprise the largest part of the domestic market. China is also likely to use the standards-setting process to compel multinationals to transfer the technology that is implicated in the standards or face the legal consequences of noncompliance.

Within the IT sector, absent a sharp change in course, China's stance toward technology acquisition is likely to evolve into a self-inflicted wound of substantial dimensions. Many, if not most, leading-edge multinational IT companies are reluctant to locate their most important R&D activities in China, although they will continue to establish R&D centers there to engage in application-specific R&D to serve local customers, and to participate in standards-setting activities. In effect, notwithstanding its status as a production base for IT equipment, China risks being "designed out" of the increasingly internationalized cutting-edge IT R&D environment, a process that has already begun.

Energy

China faces monumental long-term energy challenges. Its energy consumption is rising faster than that of any other nation, but its oil and gas resources are modest. China consumes more coal than the United States, Japan, and Europe combined. Although it has the world's third largest reserve of coal (after the United States and Russia), current demand, particularly for coking coal used for steel production, has outpaced its production, causing China to become a net importer of coal for the first time in 2007 (Yuan, 2009; Xinhua, 2009a; World Coal Institute, 2010). At present rates of extraction, China will deplete its oil in 10 years, its natural gas in 15 years, and its coal in 75 years.

As energy production struggles to stay abreast of demand, blackouts and brownouts have become common in east coast cities. Failure to satisfy China's growing energy demand could cripple China's economy and give rise to social unrest. The environmental and health effects of coal-burning are also a serious public health concern. In response to these risks, China's leaders are implementing a broad array of measures to ensure the country's energy security, while at the same time reducing pollution and carbon emissions. Key policies include a massive expansion of alternative energy sectors (notably hydropower and wind energy), widespread introduction of "clean coal" technology (China is now the world leader in building state-of-the-art coal-burning power plants (Bradsher, 2009)), expansion of nuclear energy production capabilities, and pervasive conservation efforts. With respect to scientific research, China's MLTP designates energy and the environment as priority fields for development through science and technology and through the following twofold approach:

- Acquire, adopt, absorb, and ultimately own (through indigenous IP) foreign technologies in renewable energy and pollution control
- Independently develop renewable energy and pollution control technologies in the key national research programs (MOST, 2010a,b,c)

China has decided to focus its scientific energy and environmental research on the development of technologies that reduce greenhouse gases and methane emissions or slow the processes (State Council PRC, 2008). Key themes include the following:

- Hybrid and pure electric vehicles (a major target of the 863 program)
- Technologies for renewable energy and new energy
- High-efficiency energy materials for use in batteries, hydrogen storage, and solar power systems
- Fast-neutron reactors
- Distributed energy supply technologies
- Magnetic confinement fusion technology
- Technologies for hydrogen storage, transmission, and distribution
- Energy-saving technologies
- Technologies that control, dispose of, or recycle greenhouse gases such as CO_2 and methane in major industries
- Technologies for the clean use of coal, natural gas, and oil
- Technologies for manufacturing equipment for coal and nuclear-generated power
- Technologies for controlling greenhouse emissions in agriculture

In 2008 China emerged as the world's largest producer of photovoltaic (PV) panels, accounting for about one-third of worldwide PV shipments. Although China's market for PV equipment is comparatively small, the government is implementing a number of policies to stimulate the establishment of new solar power projects, including an investment subsidy of 50 percent for grid-connected solar plants (via the Golden Sun Demonstration Program). Provincial governments in Qinghai and Yunnan are underwriting large-scale solar power plants, including a $1.3 billion, 166 megawatt solar plant in Yunnan Province (Xinhua, 2009b). The government resources being poured into this sector will virtually ensure that China remains a leading if not a dominant player in the global solar power equipment industry.

Nuclear energy production is also a top priority among China's efforts to achieve emission-free energy independence. China plans to expand its nuclear energy capacity sixfold or more by 2020, followed by another 300 percent increase by 2030. Additionally, China is rapidly progressing toward a goal of self-sufficiency in the design and production of nuclear reactors (World Nuclear Association, 2010).

The Chinese government considers the promotion of renewable energy to be crucial to national defense. The National Energy Commission, formed in 2008, is partially comprised of high-ranking military officers, a fact which has attracted widespread comment. The Chinese government has tasked the national defense production sector with developing wind power equipment for "national defense," and it has directed the industry to "facilitate the military's rapid development and advancement of the wind power equipment industry in order to build the national economy" (Xinhua, 2007; NFTC, 2010). Government R&D spending on renewable energy is generous and growing, and China is developing renewable energy equipment (such as wind equipment utilizing large magnets) that capitalize on China's near-monopoly of rare metals. China is expected to formulate standards for renewable equipment that promote Chinese standards as global standards, using the size of its domestic market as leverage. Under these circumstances it is possible that within the next two decades China will dominate one or more of the renewable energy equipment sectors that are emerging as among the most critical sectors of the 21st century.

Biotechnology

Like IT and energy, biotechnology is an emerging and rapidly changing sector in China. Although most research facilities in China remain inferior to those in the United States, newer laboratories have excellent infrastructure and equipment that rival those of their U.S. counterparts. R&D funding in the biotech area is undergoing rapid growth, providing many new opportunities for researchers. In spite of expanding resources, the quality of Chinese research and innovation in biotechnology still generally lags behind global standards, with a few pockets of excellence as reflected by recent high-profile publications in prestigious journals. Given this unevenness in research quality and outcomes, it is uncertain that the increases in biotech spending will translate into real and worthwhile innovations. As with IT, some biotechnology applications with manufacturing components, such as antibody production, are moving to China as a result of investment from both foreign and domestic companies.

This will undoubtedly strengthen the biotechnology environment and infrastructure in China, which may lay the foundation for future innovations. Overall, the biotechnology and health sector mirrors other high-tech areas in China, exhibiting rapid growth and vast potential, but many obstacles to overcome to produce real innovations.

Integration of China's S&T and Industrial Development with Defense Modernization

China's long-term strategy for modernizing its military rests on combining civil-military science, technology, and R&D into a dual-use, spin-on and spin-off system. As outlined in the MLTP, China plans to:

> Strengthen the overall planning and coordination in integrating the defense and civilian sectors . . . [and] allow for the creation of a new S&T management system embracing both the defense and civic sectors. Encourage defense-related research institutes to work on civilian research topics, while defense-related R&D activities be made open to civilian research institutes and industries. Expand the scope of defense procurement from civilian research institutes and industries. Reform the management system to ensure fair competition between non-defense and defense research institutes for defense-related research and production contracts while establishing public platforms for the integration of the defense and civilian sectors, and for dual-use applications. (State Council PRC, 2006)

The above approach to achieving military modernization, like Chinese economic reform, dates back to the early 1980s. Since then, China's military capability has steadily expanded, with defense spending increasing by more than 10 percent annually from 1989 to 2009 (Wines, 2010) and the successful test of an anti-satellite weapons system in 2007, signaling significant and controversial technological advances (Covault, 2007). An important goal in current S&T planning is the creation of an efficient defense industrial sector that is responsive to, and interacts effectively with, the commercial, academic, and military research sectors of China's S&T community.

NATION-SPECIFIC INDICATORS OF S&T ADVANCEMENT

It is evident, if only from the recent remarkable annual increases in GDP, that China is undergoing a period of rapid growth. The country's future progress will be driven by the government's desire for national prestige, self-sufficiency in S&T, economic growth, and military modernization. To assess China's effectiveness in achieving its goals, a wide range of indicators should be monitored, including those listed here:

- Number of international prizes and patents
- Emergence of international brands
- Emergence of innovative products and practices unique to China
- Level of R&D expenditures over time
- Degree and quality of connections between academic-industry-research centers
- Quantity and quality of international collaborations and exchanges in industry and academia
- Amount and type of foreign direct investment
- Continued growth and improvement of education system and faculty
- Reduction in corruption levels
- Number of publications in well-known and prestigious journals
- Successful expansion of S&T literacy into western China
- Salaries for scientists and researchers
- Trends in brain drain, brain gain, and brain circulation
- Links between mainstream innovation system and defense industrial sector

From this expansive list, a brief selection of indicators are summarized in the following sections, with priority given to those that the committee sees as particularly indicative of China's S&T advancement.

R&D Funding

There is an array of data that reflect China's economic growth over the past years and decades. It is this growth that is sustaining China's continued increases in S&T investment and infrastructure. According to the MLTP (2006-2020), China aims to raise national investment in R&D to 2 percent of GDP by 2010 and 2.5 percent by 2020, from the current percentage of about 1.5 percent. Combined with the strong growth in GDP in absolute terms, China's R&D spending has grown on average at a rate of 18 percent a year since 1995.

Although the growth in S&T funding is remarkable, there are still institutional issues that must be resolved. In particular, there is a general lack of openness and transparency in funding decisions, which negatively affects the ability of China to recruit first-rate scientists. Additionally, most R&D spending is geared toward development activities, rather than basic research. As a result, the quality and quantity of cutting-edge basic research is still small compared to that of the United States. Nevertheless, innovation in applied research and industrialization has successfully propelled China's economic growth in the past decades.

S&T Personnel

Although China's university system graduates hundreds of thousands of scientists and engineers each year, a critical shortage exists of highly qualified faculty, many of whom are attracted instead to opportunities in the private sector. This problem has given rise to new incentive programs specifically designed to attract foreign faculty and experts to teach in China. There is concern also over whether graduates have attained the proper skills needed to compete in a globally competitive environment (Simon, 2010), whether at the higher education or primary school levels. Finally, the sustained brain drain from China, to the United States in particular, continues to be a source of concern. This phenomenon is fueled by a lack of space for undergraduate and graduate students in Chinese universities, continued incentives to study abroad, attractive workplaces and improved quality of life overseas, and the ability to have a dual presence in China and abroad. Some reverse brain gains—or revolving "brain circulation"—have been realized as well, based on S&T investments in infrastructure, programs to lure back prominent scientists and others with attractive benefits packages (e.g., the Thousand Talents Program), and the increased ability to conduct research in more than one lab or location at a time.[2] Nonetheless, China seems to suffer from an overall net drain. According to a recent analysis, efforts by China to attract first-rate foreign academics have had mixed results, and on average, only about one-quarter of Chinese who went abroad for study and research have returned (Cao, 2008). Many of those that do return to China do not hold foreign doctorates; rather, they received Ph.D.s from Chinese institutions and went abroad for several years of postdoctoral research experience. The primary reason that first-rate academics have not returned to China seems to be institutional: success is often based on social connections rather than merit. This underlying factor makes it difficult for first-rate scientists from abroad who lack this professional and social network to be successful in China. Other factors include differences in work culture, the need to engage in local politics, and rampant misconduct in science. Unless these systemic institutional problems are resolved, it is likely that China will continue to experience a brain drain.

Research Publications

China's share of scientific and engineering citations grew by about 20 percent annually between 1974 and 2005. China leads internationally in publication of articles on cutting-edge technologies (e.g., nanotechnology), which contrasts with the more diverse output of papers from the United States, suggesting that Chinese scientists and engineers are pursuing technologies with defense-sector applications. Other research shows that about one-quarter of the papers attributed to China are actually the result of international collaborations, primarily with the United States (Kostoff et al., 2007). OECD data confirm the rate of growth and the significant focus on nanoscience and nanotechnology (Guinet, 2009).

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[2]The concept of "brain circulation" is credited to AnnaLee Saxenian of the University of California, Berkeley. See A. Saxenian, 2005, From brain drain to brain circulation: Transnational communities and regional upgrading in India and China, *Studies in Comparative International Development* 40(2), Summer.

Patents

China's patent outputs have risen sharply in recent years but only 1 percent are regarded as being of high value (i.e., important enough to file in advanced economies such as the United States, Europe, and Japan; NSB, 2010). Most Chinese patents are for design or utility, and only a small number are for invention (Guinet, 2009).

POSSIBLE SCENARIOS IN CHINESE S&T

From the above descriptors, we can conclude that China is well into the process of developing an advanced national innovation system and is endeavoring to expand this capability across its vast territory. The future of this venture is as yet unclear, as is China's capacity to provide the necessary tangible and intangible S&T infrastructure (skilled researchers, educators, enterprises) that will be necessary to support an expanding national innovation system, especially in less-developed parts of the country, over the next several decades.

Several fundamental questions remain: Can China achieve its economic and S&T modernization goals? If so, what then? Will China turn inward and/or continue to engage globally? Will China develop an innovation system that is based on the Western approach, or will China develop a more distinct and evolving innovation system and style? These appear to be fundamental but as yet undecided dilemmas even for Chinese decision-makers. Given the high levels of uncertainty about China's current and future S&T environments and where it might be headed, it can be predicted that the trajectory for Chinese S&T innovation will fall into one of three general categories: upward trajectory; downward trajectory; or somewhere in the middle.

Under the first scenario, China becomes a global as well as a regional S&T and R&D hub and a global technology standards competitor, if not leader, in key sectors. Modern facilities built around innovation-technology-education clusters, particularly in China's eastern provinces but also its central areas, prove both attractive and essential to multinational corporations as well as to leading international researchers and scientists, who in greater numbers conduct operations and advanced R&D in China on at least a part-time basis. Both multinational and domestic R&D centers develop increasingly innovative products and processes, including Chinese-developed components, that have a growing impact on the Chinese and global markets. Finally, China closes in on or achieves its goal of one of its scientists being awarded a Nobel Prize in Science (the lack thereof being a growing irritant and challenge to China's status as a global S&T leader) and emerges as an innovative challenger or leader in new technology fields/sub-fields. China improves its capacity to develop and produce components for Western commercial and defense industries.

Under the second scenario, national technological standards and practices increasingly isolate Chinese industry and scientific communities from global trends, ideas, and leading innovative processes. China's leading technologists and scientists are engaged globally but indirectly, because of fewer close industrial partnerships or collaborative ventures. Over time, China's spurt in S&T innovation slows or stalls, and advanced foreign investment and interest diminishes and diverts to other global hot spots. Western commercial firms and defense industries remain engaged with, but wary of and generally unchallenged by, Chinese counterparts.

In the third scenario, China's efforts to develop a national innovation system are somewhat successful but confined mainly to the eastern provinces. Central and western provinces fall short of China's aspirations in developing R&D bases and competitive techno-industrial clusters. China's education system remains a critical obstacle to faster, more advanced S&T and R&D capabilities that are commensurate with Western advances and remains reliant on inputs from foreign experts. The world's leading scientists collaborate with their Chinese counterparts, but mainly in areas of mutual interest or in promising new areas of exploration and often as part of larger international teams. Overall, innovative and inventive abilities trail global standards. However, China remains a key supplier to the West of Chinese-produced components that it grows slowly and sporadically as a producer of Chinese-designed parts and, potentially, systems.

The outcome of the above scenarios could be significantly affected by the following internal and external factors:

- **Corruption.** Current surveys suggest that corruption is endemic across China's scientific and industrial communities and undermines China's interaction and integration with international counterparts.

- **Export controls and Tiananmen sanctions.** If current barriers to Chinese access to advanced Western dual-use and munitions technologies are lowered or eliminated, then new S&T and R&D possibilities will emerge for Chinese commercial and defense industries. However, this might diminish China's current enhanced capabilities at systems integration, due in part to the necessity of technologically integrating diverse sources of dual-use foreign technology into new, Chinese-made products or components.
- **Resource competition.** As with other powers, China's future scientific and technological advancement is heavily reliant on continued access to critical material and minerals, whether through domestic supply, stockpiling, and/or import. The competition for rare earth elements is already underway; China is a significant competitor by virtue of its U.S.-size demand and market. If resource availability becomes a strategic restriction on global S&T, this could seriously impact which of the above scenarios comes to pass.
- **Globalization advances to incentivize offshored or outsourced S&T.** Globalization may begin to affect the scientific community such that, much like industry R&D, scientific fields of study become modularized across a global innovation community based on different states' comparative advantages. China could stand to benefit considerably from such a trend and may seek to promote it. China's size, investments, aspirations, and potential in terms of S&T would likely make it a highly attractive base for a more globalized scientific community, particularly in basic sciences.

FINDINGS AND RECOMMENDATIONS

The pace and extent of China's S&T achievements have been surprising to most observers, including China's own experts. There remain several unpredictable factors that could seriously disrupt or reverse China's progress and could, in turn, impact U.S. national security interests. This uncertainty slows the ability of government, industry, and academia to understand, effectively respond to, and leverage such rapid and dramatic changes and represents a critical challenge to leveraging the emerging global S&T landscape.

Finding 4-1. Because of its size and economic role, China's future outcomes have great potential impact on the global economy and on U.S. national security—but, lack of knowledge about the direction of China's future development makes it difficult to predict the extent of the impact.

It is highly likely that China will continue to advance its S&T capabilities at a fast pace and on a large scale for years to come. Additionally, the size, scope, and potential of China's human resources, level of government spending, market size, and territorial breadth represent a critical competitive advantage that few other countries possess (the United States being a notable exception). China benefits from having many opportunities for S&T collaboration and, barring an unexpected upheaval, will likely continue to benefit from them for many years. The present and prospective level of national and international S&T interaction taking place in China (by both Chinese and non-Chinese), therefore, holds the potential for possible S&T breakthroughs that are multidisciplinary and transformative in nature. The more open China is to international S&T and R&D, the greater the risk that China will become not only an S&T competitor but also an S&T alternative to the United States among countries and corporations. This would represent a threat to continued U.S. S&T leadership.

Finding 4-2. If China can continue to increase its openness to, and opportunities for, international collaboration while providing access to its human and economic resources and ensuring the protection of intellectual property, then it could become a substantial S&T competitor to the United States and a destination for basic S&T for other countries and corporations, which would constitute a threat to U.S. national security.

Recommendation 4-1. The United States should actively seek out opportunities to leverage China's S&T advances, resources, and networks and foster closer cooperation and integration where it serves U.S. national interests.

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5

India

India's ambitious but not likely achievable goals are to become a developed nation through the use of science and technology (S&T) by 2020, rank within the top five globally for gross domestic product (GDP), and provide a developed-world standard of living. India has sustained both population growth and economic growth during the past 10 years, enhancing its domestic purchasing power and standard of living. Although its market is large, India remains a poor country with 80 percent of the population living on less than $2 per day. Its large English-speaking population has limited access to a first-tier S&T higher education. Its legal and financial systems are strong. The democratic government is highly bureaucratic, and new governments are formed about every five years. Its five-year (only) S&T plans place priority on reducing dependence on foreign technology through indigenous innovation. Security concerns about neighboring countries and protecting the coastline make development of dual-use technologies (such as nuclear technology, space and ocean exploration) a high priority. Developing capacities in health and agricultural technologies, information and communication technologies, biotechnology, and nanotechnology is also a priority. Obstacles to India's advancement include high levels of poverty and a widening income gap, loss of talent through brain drain, a poor basic infrastructure, especially in rural areas, low agricultural productivity and literacy, little engagement of industry with research or research universities, and limited access to education and basic resources such as food, water, and medicine. The United States should support Indian growth and should strengthen the existing U.S.-India alliance.

INTRODUCTION

India is widely recognized as a rising economic power. A decade of economic progress has propelled the second most populous nation in the world to command the fourth largest economy in terms of purchasing power (CIA, 2010), with GDP increasing by an average of 9 percent annually in the fiscal years 2004 to 2008.[1] This remarkable growth has been accompanied by a pronounced rise in the purchasing power of the Indian middle class, fueling the expansion of domestic commercial markets, even though income inequality is growing, and poverty is still widespread. In addition to its large domestic market, India possesses many strengths that will play a crucial role in its achievement of major development goals: a young and growing population with expanding

[1]Although GDP growth dropped to 6.7 percent in 2009 in response to the global economic crisis, growth has rebounded and is expected to continue in the 2010-2011 fiscal year (Jagota and Kala, 2010).

access to education and jobs (Bloom et al., 2003), a strong private sector with experience in market institutions, a well-developed legal and financial system, and a large science, technology, and research infrastructure. Another advantage is the country's population of highly trained English-speaking engineers, scientists, entrepreneurs, and other professionals.

Countering India's strengths are the many social, political, and economic obstacles with which it must contend. India remains a relatively poor country, with per capita income below $700, a less than 2 percent share of global GDP, and only a 1 percent share of world trade. Moreover, 80 percent of India's population lives on less than $2 a day, with more than 50 percent of the total labor force still engaged in agriculture (CIA, 2010). Barriers to further growth and development are many and include limited infrastructure and access to water, food, and medicine, widespread illiteracy, threatened national security in the face of regional and ethnic tensions, and stifling government bureaucracy.

India has long embraced science and technology (S&T) as a means to improve the national economy and the lives of its citizens. This continued political commitment is documented on a basic level in the Scientific Policy Resolution of 1958, the Technology Policy Statement 1983, and the 2003 Science and Technology Policy of the Government of India. These three initiatives have led to the creation of a vast S&T infrastructure within government research and development (R&D) institutions, universities, nongovernmental organizations, and industry.

India's system for S&T innovation is comprised of central and state government agencies as well as public and private organizations. However, the most significant role is played by the government, with a large number of organizations functioning under central government S&T departments. Figure 5-1 illustrates this organizational structure.

The Indian government is responsible for about 74 percent of national R&D expenditures; of that, the central government is responsible for the greatest share. The industrial sector (public and private) accounts for about 30 percent of total expenditures. The government has encouraged greater participation from the industrial sector over the past five years, which has led to a small increase in private R&D funding, although more is needed to meet larger S&T objectives.

Within India, there are about 400 national laboratories, 400 R&D institutions in the government sector, and about 1,300 R&D organizations in the industrial sector. About 400,000 personnel are employed in R&D establishments. India's more than 300 universities and educational institutions produce more than 450,000 S&T personnel every year. However, at this stage, many of these institutions devote few resources to research, focusing primarily on development. Recognizing that India's skill base is growing, more than 300 multinational companies have opened their R&D centers and laboratories in different sectors of the economy (World Bank, 2007). Some corporations have formed alliances with Indian institutions for joint research projects. Indians also continue to go abroad for education and business, and they are building networks for S&T through the private sector, using new business models and creative value creation.

NET ASSESSMENT OF S&T INVESTMENT STRATEGY

India has not published a multi-year, long-range S&T plan. However, India's planning commission has issued five-year plans since independence was achieved in 1947, each of which contains an important section on S&T. The plans discuss accomplishments and issues during the previous five years and propose initiatives for the next five years. Although India's five-year plans offer flexibility, they provide little specific guidance on long-term S&T goals. Because the country is a democracy, the lack of stated long-term goals leaves India's S&T strategy more vulnerable to interruption or dilution as a result of changes in administration.

India has a stated goal of becoming a developed nation by 2020, ambitiously aiming to be one of the top 5 countries in the world in terms of GDP. The five-year plans highlight S&T as a contributor to this long-term vision. The current plan (2007-2012) lays out a broad strategy for improving the national S&T environment by enlarging the pool of scientific manpower, encouraging risk taking on the part of scientists, supporting creativity in the education system, celebrating both basic research and applied research and technology development, encouraging industry to interact with academia, and providing incentives for young people to pursue scientific careers. Finally,

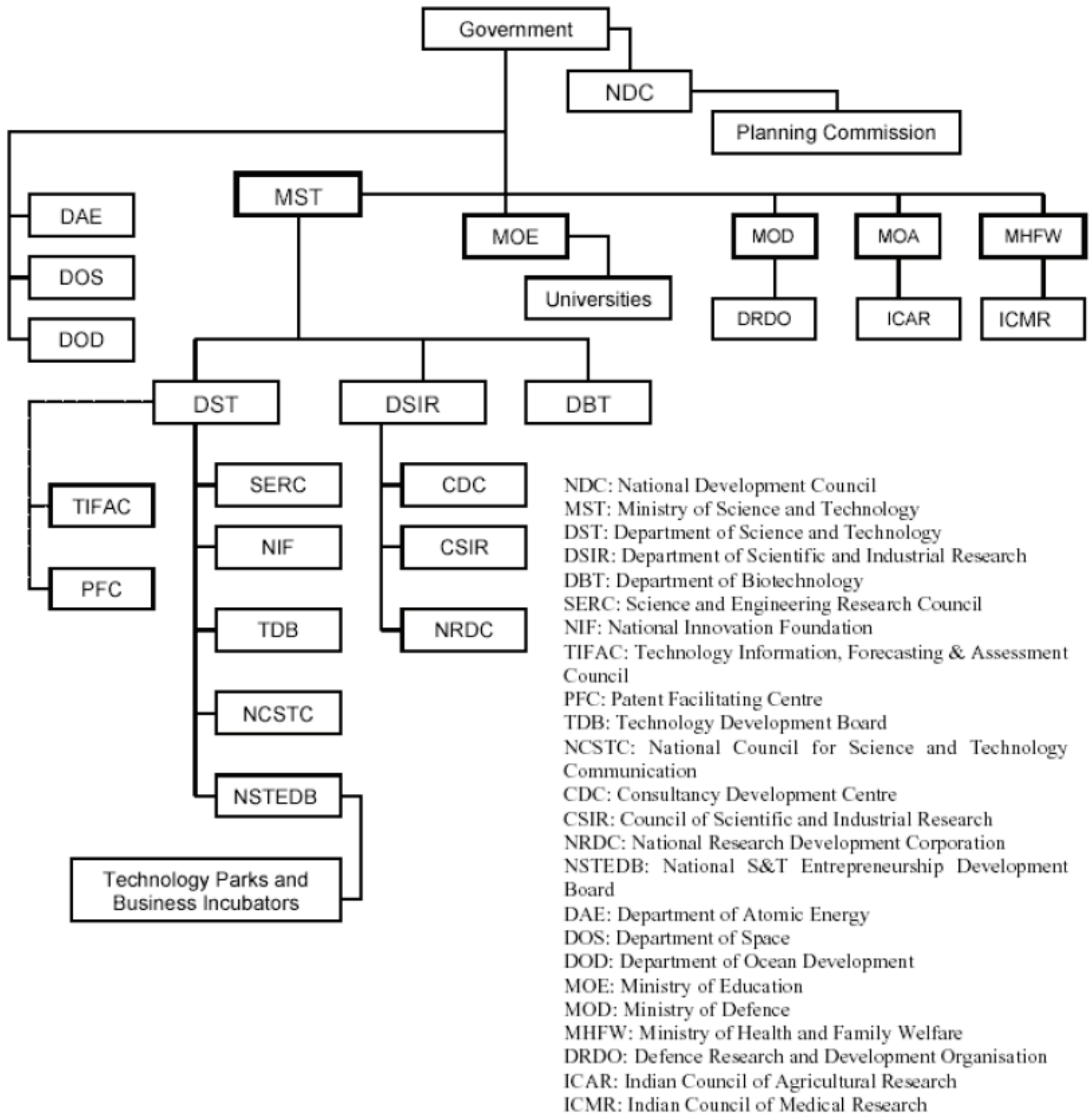

FIGURE 5-1 Government organizations functioning under central government S&T departments in India.
SOURCE: Country Report for India 2007, PRO INO Europe.

the plan also recommends that scientific developments in the rest of the world be surveyed to assist in the selection of critical technologies for prioritized investment.

Defense is also a national priority. The Sino-Indian War in 1962 and two subsequent wars with Pakistan in 1965 and 1971 made deep impressions on the Indian psyche. India now has the third-largest military force in the world. Although it maintains a “no first use” nuclear policy, India became a nuclear power in 1974 and has since expanded its nuclear capabilities.

A review of previous five-year plans reveals the continuation of strategies in key technology areas, which indicates that there is a long-term strategy, even though it is not documented beyond five years. The current five-year plan identifies detailed research foci and envisioned outcomes for 16 sectors with the greatest proposed national laboratory funding in the following areas, in descending order: aerospace, pharmaceuticals, materials, information technology, biology, earth systems and exploration (including on- and off-shore geophysical studies), and energy (DST, 2006a). The central government of India funds nearly 60 percent of S&T expenditures, making it the largest single contributor to India's innovation system. Within central government funding, atomic energy and space and ocean exploration are emphasized. In addition to promoting S&T advancement, these three areas present dual-use opportunities. For example, atomic energy provides India with energy independence, but the technology can also be used for nuclear weapons development. Another national goal is to develop indigenous technologies to protect itself from denial of technology (by other countries).

India, like many of the other countries examined in this report, suffers from a lack of connection between scientific R&D and industry. Industry in India does not sponsor students and educational programs to the degree that many other countries do, most notably the United States. The Indian government is trying to address this. In the current five-year plan, one goal is to improve interaction between industry and academia and to encourage students to pursue science and engineering, emphasizing both basic and applied research.

Although the above goals and strategies might appear rather generic, the goal of making India a developed country by 2020 provides a vigorous focus for India's scientific efforts. Phrases like "risk taking," "creativity," "glorification of applied research," and "interaction between industry and academia" have become new additions to Indians' everyday lexicon.

PROJECTED ADVANCES IN S&T PROFICIENCY

It is doubtful that India will achieve its goal of reaching the top 5 in global GDP by 2020. Other stated goals include the increase of R&D expenditures from 0.9 percent to 2 percent of GDP and to increase education spending from 4 percent to 6 percent of GDP. Increases have been made, but it will likely take more than 10 years to achieve these goals, due to other challenges resulting from poverty and lack of infrastructure.

Administration changes every five years can have a significant impact on S&T direction and funding. Ministers can request funding for their constituencies, but they are guided by the India Administrative Services, a process that provides stability.

Weaknesses in the Indian education system, including large discrepancies in the quality of education between top institutions and departments and the rest of the Indian institutions, could potentially slow the growth of the S&T innovation system and prevent some goals from being achieved within their projected timelines. Recognizing the need to increase educational resources, the Indian government recently presented to the Parliament the Foreign Educational Institutions Bill, which allows foreign universities to establish campuses in India (Government of India, 2010). It is hoped that passage of the bill will spur an increase in the number of top-quality institutes in India and will offer students an alternative to traveling overseas for education.

S&T INVESTMENTS OF INTEREST

India's technology requirements are vast and imply great utility for a wide variety of scientific fields from nuclear energy to agricultural science. "Technology Vision 2020," a strategy document prepared by the Technology Information, Forecasting and Assessment Council's of Department of Science & Technology, lays out a recommended set of actions that India should undertake to become a developed nation by the year 2020. It identifies five broad areas for development that can best leverage India's core competencies and address its critical needs: agriculture and food processing, infrastructure with reliable electric power, education and healthcare, information and communication technology, and "critical technologies" (defined as nuclear, space, and defense).

Key Programs Under the 11th Five-Year Plan

The following are some of the key programs of the six major scientific departments that are specified in the 11th Five-Year Plan.

Space

The plan calls for completion of the development of the Geosynchronous Satellite Launch Vehicle Mark III (GSLV-III), which is capable of launching a 4T class INSAT satellite. Other goals are to perform demonstration flights of the Reusable Launch Vehicle and to develop the critical technologies required for a manned mission.

Biotechnology

India's goals for biotechnology focus on specialized research in areas such as stem cells, animal biotechnology, and plant health. However, most efforts are geared toward short-term realization of diagnostics. There is little that is original, but much that is useful.

Ocean

Priorities for this program include the demonstration of ideal coastal protection measures, as well as advancements in ecosystem modeling, marine ecotoxicology, and carbon cycling in coastal waters. The plan calls for the preparation of a Coastal Risk Atlas that would serve as part of a national Tsunami Early Warning System and the establishment of an Advanced Research Centre for Drugs from Ocean.

Atomic Energy

India's overarching goals in the area of atomic energy are to improve the utilization of nuclear capacity and to enhance the economic competitiveness of nuclear energy with an eye to safety and the environment. Specifically, goals are to upgrade current technology based on latest developments in the pressurized heavy-water reactor (PHWR) fuel cycle, and to set up fast breeder reactors, backed by reprocessing plants and plutonium-based fuel fabrication plants, a move that has raised reasonable and serious concerns over the increased availability of plutonium to terrorist organizations and for nuclear weapons proliferation. The plan also calls for the establishment of thorium on a large scale for the next stage of the nuclear power program.

Council of Scientific and Industrial Research (CSIR)

A major initiative of the CSIR is to develop an open-source drug discovery program through national and international collaborations between national laboratories and academia.

Department of Science & Technology (DST)

The goals for the DST underscore India's need for improvements in basic infrastructure, particularly in rural areas. Specifically, the plan calls for new initiatives in the technologies for security and safe drinking water, and for the establishment of a National Foundation for Technology for Rural Enterprises and Employment.

Major Accomplishments During the 10th Five-Year Plan

In order to understand India's current areas of focus, it is helpful to study the accomplishments highlighted in the past five-year plans (DST, 2006b). The 10th Five-Year Plan, completed in 2007, was considered by many to be an enormous success. Its accomplishments include the commissioning of two 540 MW indigenously designed PHWR, the first light from the Indus-2 synchrotron, and the debut of a countrywide environmental radiation monitoring network with 37 monitoring stations across the country. Substantial progress has been made in satellite technologies, beginning with the operation of the Geosynchronous Satellite Launch Vehicle (GSLV), the development and qualification of an indigenous cryogenic rocket engine (the most powerful rocket engine in current development[2]), and the establishment of the state-of-the-art second launch pad facilities at Sriharikota. Several satellites were placed in operation, including the KALPANA-1 (Metsat-1), Resourcesat-1, and Cartosat-1/HAMSAT, and the INSAT system was augmented with the launch of INSAT-3A, 3E, GSAT-2, EDUSAT, and INSAT-4A satellites.

Other scientific achievements include the following:

- Installing early tsunami and storm surge warning system
- Strengthening the ocean observation network by deployment of state-of-the-art technology data buoys and Argo floats
- Completing the maiden flight of SARAS, a multi-role civilian aircraft
- Beginning the Nano Science and Technology Initiative
- Forming a new Ministry of Earth Sciences for programs related to Earth and atmospheric sciences

India continues to develop atomic energy and space technology. New research areas include biotechnology and nanotechnology.

NATION-SPECIFIC INDICATORS OF S&T ADVANCEMENT

India's progress in S&T development can be assessed using traditional indicators such as the level of R&D funding, human resources devoted to R&D activities, spending on higher education and graduation rates, and number of research publications and patents (including those that result from collaborations between universities and industry). Together, these metrics give a sense of India's commitment to the advancement of S&T and of the efficiency of the S&T enterprise. A detailed breakdown of these indicators can also shed light on S&T priority areas. Other appropriate indicators are the levels of foreign investment in R&D, the influence of published papers (indicated by their inclusion in high-quality conferences or journals), and the number of highly educated citizens that return from abroad to work and live in India.

Although absolute numbers are important, trends in indicators over time can often be even more illuminating. In this respect, all selected indicators show that India is on a positive trajectory.

R&D Funding

The national expenditure on R&D increased from about $180 billion in 2002-2003 to about $280 billion in 2005-2006. R&D expenditures were expected to reach a level of $330 billion in 2005-2007 and $380 billion in 2007-2008. R&D expenditure as a percentage of gross national product (GNP) in 2005-2006 was 0.89 percent, compared to 0.81 percent in 2002-2003. The government of India wants to increase R&D spending to 2 percent of GNP, but it remains to be seen whether this target will be achieved.

Human Resources

In April 2005, nearly 390,000 personnel were employed in the R&D establishments, including in the industrial sector. Some 40 percent of them were performing R&D activities, 27 percent auxiliary activities, and 33 percent administrative and support activities.

A large fraction (49 percent) of R&D personnel was employed in the government sector (major scientific agencies: 31 percent; central government ministries/department: 6 percent; state governments: 12 percent). The academic sector (higher education) employed 14 percent. The industrial sector, comprising both public and private industries, employed the remaining 37 percent at 6 percent and 31 percent, respectively (DST, 2008).

[2]India's first cryogenic rocket engine was used in a failed mission on April 15, 2010. If India executes a successful launch, then it will join the United States, China, France, Japan, and Russia in the small group of countries possessing this technology. For more information, see http://timesofindia.indiatimes.com/articleshow/5811717.cms. Last accessed June 3, 2010.

Among R&D personnel, 17.5 percent were Ph.D.s, 38.2 percent post graduates, 30.3 percent graduates, and the remainder diploma holders (DST, 2008).

Although informative, these gross statistics do not communicate the fact that the variance in skill levels and quality of personnel in India is generally large.

Higher Education

Any analysis of data regarding the Indian education system must take into account its dual nature, with world-class institutes coexisting with others that have inadequate resources and are only able to impart education at barely satisfactory levels.

In 2005-2006, there were 358 universities, 13 institutes of national importance, and 20,677 colleges offering higher education. Of the 11.6 million students enrolled in higher education, 31.6 percent studied science and engineering. Also in 2005-2006, 18,730 Ph.D.s were awarded, of which 45 percent were in science. Within the science discipline, 66.8 percent of Ph.D.s were awarded in pure sciences, 13.3 percent in agriculture sciences, and 12.6 percent in engineering/technology.

The proportion of students completing higher education and in particular doctoral studies was very small; only 0.034 percent of the total school-going population was enrolled in a Ph.D. program in 2006.

Public expenditures in the education sector equalled 1.52 percent of GDP in 1961-1962, which increased to 3.68 percent by 2004-2005, and to 4.4 percent currently. Expenditures on higher education as a percentage of GDP was 0.77 percent in 1990-1991, which decreased to 0.62 percent in 1997-1998, and then rose slightly to 0.66 percent in 2004-2005. The Indian government wants to increase the total spending on education to 6 percent of GDP. Again, it remains to be seen whether this goal will be achieved.

Research Publications

Authors in India published about 323,000 research papers during 1997-2007 (about 30,000 papers per year). The cumulative number increased from about 65,600 papers during 1997-1999 to 121,500 papers during 2005-2007, resulting in a growth rate of 85 percent (NISTADS, 2009).

India's share in global publications increased from 1.86 percent in 1997, to 1.97 percent in 2002, and to 2.55 percent in 2007. Correspondingly, India's ranking rose from 13th in 1997 to 12th in 2002 and to 10th in 2007. By way of comparison, the United States published more than 3.5 million papers during 1997-2007, and its share of global publications was 23.4 percent (NISTADS, 2009).

Of the total papers published by Indian researchers from 1997 to 2007, 15 percent were the product of international collaboration. The United States was the leading collaborator, contributing to 37 percent of India's collaborative papers (NISTADS, 2009).

Patents

Following a 1995 national campaign to create awareness about intellectual property, India's patenting output increased from about 1,000 in 2001 to nearly 5,500 in 2007. Industry's share of patents increased from about 40 percent of total patents in 1990-1999 to about 60 percent of total patents in 2000-2007. The leading assignees from the private sector were the drugs and pharmaceuticals companies, which obtained more than 3,600 patents in 2000-2007 compared to about 100 in 1990-1999 (NISTADS, 2009).

Indian firms have been filing for foreign patents at a steadily increasing pace. The number of countries in which Indian firms obtained patents rose from 29 in 1990-1994, to 52 in 2000-2004, to 101 in 2005-2007. Until 2004, most of the foreign patents were filed in the United States and Canada, after which the patenting activity expanded to Europe, Asia, and Latin America continents (NISTADS, 2009).

A significant number of Indian patents are in the areas of chemistry, chemical technologies, and drugs and pharmaceuticals. Other areas include food products and technology, micro-organism and genetic engineering, information and communication technologies, optical computing devices, digital data processing, and telecommunication.

CONCLUSION

High Aspirations and Unifying Vision

India's foremost nuclear physicist and former President Dr. Abdul Kalam articulated India's aspirations most succinctly: "Become a developed country by 2020 through the use of science and technology" (Kalam et al., 1998). India's plan of action includes broadening access to healthcare and education, improving food, water, and energy security, and constructing a national network of roads and railways (Planning Commission, Government of India, 2002). This simple vision has become a rallying cry and has galvanized policymakers, scientists, technologists, academics, entrepreneurs, administrators, and politicians to develop and implement actionable plans and programs.

Increasing Confidence in Indigenous Capabilities

India's indigenous research has produced several recent successes: (1) simultaneous launch in April 2008 of 10 satellites on an indigenously built Polar Launch Satellite Vehicle, (2) launch in October 2008 of the moon mission *Chandrayaan-1*, and (3) launch in July 2009 of India's first nuclear-powered submarine Indian Navy ship, called *INS Arihant*, demonstrating that India now has compact power plants for propulsion and pressurized water reactor (PWR) technology for future electricity production.

Emergence of Globally Competitive Business Enterprises in Automotives, Pharmaceuticals, Information Technology, and Telecommunications

Reflecting the growth of India's middle class, the Indian automobile manufacturer Tata launched the world's cheapest small car, the Nano, in 2009. In the same year, Mahindra and Mahindra launched Scorpio, an indigenous sport utility vehicle. India's pharmaceutical industry is also globally significant, ranking 4th in the world in terms of production volume and 13th in terms of value. India now supplies 22 percent of the world's generic drugs and a significant proportion of the vaccines made for the developing world (World Bank, 2007). Moreover, Indian pharmaceutical firms have progressed from the production of generic drugs to the manufacture and testing of new and experimental treatments. The Indian pharmaceutical industry plays a key role in global initiatives such as the International AIDS Vaccine Initiative and the Global Fund to Fight AIDS, Tuberculosis and Malaria. A disruption in India's drug supply could result in substantial public health problems and even civil unrest in the populations that rely on it.

Information technology (IT) continues to be a booming industry in India, even amidst the current economic crisis, with some sources estimating that Indian IT firms such as Infosys and Wipro will have grown by more than 18 percent between 2006 and 2011 (Newstrack India, 2008). The telecommunications market is also experiencing rapid growth, with more than 10 million new mobile phone subscribers every month (TRAI, 2009). In June 2010, Bharti Airtel Limited, an Indian telecommunications company, finalized a deal with the Kuwaiti-based Zain, giving it access to growing African telecommunications markets (Rajan, 2010). Because innovation provides the foundation for success of these enterprises, Indian companies are increasingly inclined to invest in indigenous R&D to maintain their competitive edge.

Suspicion of Neighboring Countries and Fear of Technology Denial

Right or wrong, India feels surrounded by hostile neighbors and is fearful of becoming dependent on other countries for strategic technologies. As a result, India spends a disproportionally large amount on R&D in the government sector and on defense technologies. The inefficiency and waste in the current allocation of R&D

resources is well recognized, and government wants private industry to bear a greater share of R&D investment. However, change is likely to be gradual at best.

Inefficiency in Innovation

India lags behind both China and Brazil on many traditional S&T indicators, including the number of R&D researchers per million inhabitants, the number of patents granted per million inhabitants, R&D spending as a percentage of GDP, and high-tech exports as a percentage of manufacturing exports (World Bank, 2009). India suffers from inefficiency in transforming its S&T investments into scientific knowledge (publications) as well as into commercially relevant knowledge (patents). In addition to the structural issue of having a large portion of S&T work located in the government sector, the loss of top talent to developed countries also contributes to inefficiency. Data suggest that some of the best Indian students go abroad for higher education and never return, thus in effect reducing the quantity and quality of the pool of qualified S&T researchers and educators in India (NRC, 2007). Multinational corporations conducting business in India further aggravate this trend by luring away bright Indians from research careers.

Development Challenges

In spite of tremendous progress in recent times, India continues to face challenges that could derail its S&T aspirations. There is a large gap between the installed capacity and projected needs in basic infrastructure, including power, roads, telecommunications, seaports, and airports. Agricultural productivity and literacy are low, and societal problems such as poverty, public health, and population growth have proven hard to crack. Frequent policy changes, shifts in the governing alliance of political parties, and stifling government bureaucracy compound the problem. The government of India wants to increase the investment in education to 6 percent of GDP and in research to 2 percent of GDP, but these goals might become hard to realize in the face of other development challenges.

Implications for the United States

Clearly, the United States can contribute tremendously to strengthening the Indian innovation system and to helping India realize its vision of becoming an economically developed country. Many U.S. companies already have large investments and technological alliances with companies in India, and many Indian companies provide technological services in the United States. There are many collaborations between academics and researchers in the two countries. Since the signing of the U.S.-India Civil Nuclear Cooperation agreement in October 2008, the climate for collaborations between the two countries has never been better. Also beneficial to the prospects of future cooperation is the strong affinity most Indians feel with the United States. Like the United States, India is a democratic and pluralistic society, and a large Indian diaspora exists in America. The challenge for the future is how to make the current U.S.-Indian relationship deeper and extend it to the strategic sector.

FINDINGS AND RECOMMENDATIONS

Finding 5-1. India has increasing aspirations to become a major global player (i.e., become a developed nation by 2020).

Finding 5-2. India has had recent successful demonstrations of indigenous capabilities (nuclear power, satellite launches, multi-use launch vehicles).

Finding 5-3. India still faces significant developmental challenges including low spending on S&T and education and limited rural development. Disparity in the educational system between the top-tier Indian Institutes of Technology (IITs) and the second-tier institutions is significant. Although India’s population is large, relatively few students have access to a quality education.

Finding 5-4. A number of India's S&T initiatives and self-reliance goals are based on a fear of technology denial. A tense relationship with Pakistan and a fear of technology denial from global partners has prompted India to pursue indigenous technology and capability development.

Finding 5-5. Cross-fertilization between the United States and India exists through industry partnerships and personnel exchanges exist. Many Indian students attend university in the United States; student and professor exchanges between India and the United States are quite common. The existing relationship between the United States and India is ripe for continued support and exchange.

Recommendation 5-1. The United States should deepen its S&T relationship with India and expand collaborations in programs such as nuclear power and space technology.

Recommendation 5-2. The United States should support India's educational improvement in the critical infrastructure area. Support by the United States to improve Indian education would provide an increased talent pool to support Indian and global innovation, while increasing trust and collaboration between India and the United States. India is a stable democracy in Asia, and continuing and improving a strong S&T and educational relationship may help build better democratic traditions in the region.

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6

Japan

For the past two decades Japan has struggled to return to the robust levels of economic growth it enjoyed after World War II. It remains a world leader in high technology and views science and technology (S&T) as critical to economic revitalization and national security. Japan has increased research and development (R&D) funding levels and has undertaken a series of major reforms in its S&T infrastructure that are designed to improve industry-university-government collaboration and to spur innovation. However, these reforms have been implemented slowly and have not addressed longstanding fundamental weaknesses in Japan's S&T system, which include immobility of personnel, inadequate entrepreneurialism, insufficient opportunity for younger researchers, and abiding problems with industry-university-government collaboration. With respect to national security, Japan's leaders are prioritizing missile defense and the prospect of competition over resources in nearby waters. Major S&T efforts are underway to address concerns over raw materials (particularly rare-earth elements), energy and food availability, and prospective epidemics. Japan's aging population, low rates of birth and immigration, and low participation of women in the workforce will act as a drag on its future S&T efforts. The United States should strengthen its existing relationship with Japan and should support Japanese R&D efforts.

INTRODUCTION

In spite of its small land mass and limited resources, Japan surprised the world with its use of S&T to propel itself from a relatively undeveloped country (prior to World War II) to a major manufacturer, a global innovator, and currently the world's second-largest economy. The 1991 burst of the market bubble that fueled much of Japan's sensational growth in the 1980s began a trend of deterioration in the national economy. Although still prosperous, the nation is engaged in steady reform intended to preserve the gains it has already achieved while laying the foundation for a secure future. The ultra-competitive and rapidly changing nature of the East Asian marketplace will pose challenges for a country used to regional dominance.

Since the early 1990s, Japan has been overhauling its science establishment with the objectives of restoring the economic growth that it enjoyed throughout the 1980s and of promoting innovation. Nevertheless, these reforms have been implemented at a very slow pace, meaning they will take a number of years to begin to have observable effects, and they may be impeded by numerous structural aspects of Japan's economy and society that create obstacles to innovation and limit Japan's participation in the global R&D community. In the realm of national security-related R&D, Japan places high priority on developing specific technologies and production processes to address perceived military and nonmilitary security threats, including satellite warning and monitoring systems, rockets, nuclear reactors, scanners, advances in fertility with respect to crops and marine life, alternative energy technologies, and alternatives to rare-earth metals needed in industrial processes.

Although growth in Japan's GDP averaged 4 percent per year between 1975 and 1990, it declined to an average of 1.3 percent per year in the following decade (Motohashi, 2005). Alarmed by its stagnating economy, Japan introduced new innovation policies in 1995, which were aimed at revitalizing its innovation capability and energizing its economic growth. The new policies, modeled in part after similar policies in the United States, included major reforms to improve S&T partnerships between universities and industry, and the enactment of a new intellectual property (IP) policy allowing universities, small businesses, and nonprofits to claim ownership of innovations developed with federal funds (akin to the Bayh-Dole Act of 1980 in the United States). In addition, the budget for funding S&T research was increased significantly; in 2007, Japan's total R&D expenditures equaled 3.67 percent of its gross domestic product (GDP), the highest among industrialized nations (compared to 2.68 percent in the United States), with a 5 to 1 ratio of private-sector to public-sector spending.

NET ASSESSMENT OF S&T INVESTMENT STRATEGY

In Japan, several ministries are involved in S&T policy, but coordination is managed by a cabinet office called the Council for Science and Technology Policy (CSTP), which reports directly to the Prime Minister. Attention to S&T policy at the executive level gives Japan a potential advantage relative to other industrialized nations in terms of enacting transformational policies with long-term impact on research, education, and technology innovation.

Japan's S&T planning is closely linked to perceived threats to security, each of which is the subject of one or more national-level R&D projects. The most urgent concern, a ballistic missile attack from North Korea, is the subject of a high-priority R&D effort to improve early warning capability through the development of a new generation of high-performance satellites and launch vehicles. The threat of terrorism originating abroad is being addressed through the development of satellite surveillance capabilities for all of Japan's territories and the development of portable scanners for inspection of luggage. Japan's concerns over energy and resource security are the subjects of R&D projects to enhance its ability to access seabed resources, drastically curtail energy consumption, produce energy from biomass, and develop technological alternatives to rare-earth elements. The latter initiative is of particular importance because China currently accounts for 97 percent of global rare-earth-element production and is restricting export quotas in response to growing domestic demand. Japan is also engaged in efforts to secure its future rare-earth-element supply through stockpiling and acquiring foreign mines (Hurst, 2010). Threats to food security are being addressed through R&D programs to improve crop yields in poor environments and to replenish the dwindling population of fish in nearby waters. Although the close linkage of Japan's security concerns to specific threats is impressive, the country's ability to contain these threats through S&T is questionable, reflecting weaknesses in Japan's S&T infrastructure.[1]

Institutional Reforms

Japan changed its funding model for research by increasing the fraction allocated to competitive funding; between 1991 and 2005, that fraction increased sixfold. Equally significant was Japan's move (starting in 2004) to separate its national universities and research institutes from the government's civil service system, thereby giving them more autonomy to define their roles and allocate their resources, and more freedom to work cooperatively with industry. This policy will likely pay great future dividends to Japan in the form of enhanced research productivity and an environment that is more conducive to technological innovation.

[1]Many of these weaknesses are acknowledged in Japan's Science and Technology Basic Plan (2006) in the form of objectives for "Reforming the S&T System." They include "creating an environment where individuals thrive," "supporting the independence of young researchers," "improving the mobility of human resources," "suppressing the rate of inbreeding in faculties," "promoting the activities of female researchers," "drastic enhancement of graduate education," "promoting the activities of foreign researchers," "resolving the institutional and operational bottleneck that acts against S&T activities," "reforming the research fund system beyond office and ministries," "developing industry-government-university trust," and "promoting the entrepreneurial activities of R&D ventures" (CSTP, 2006).

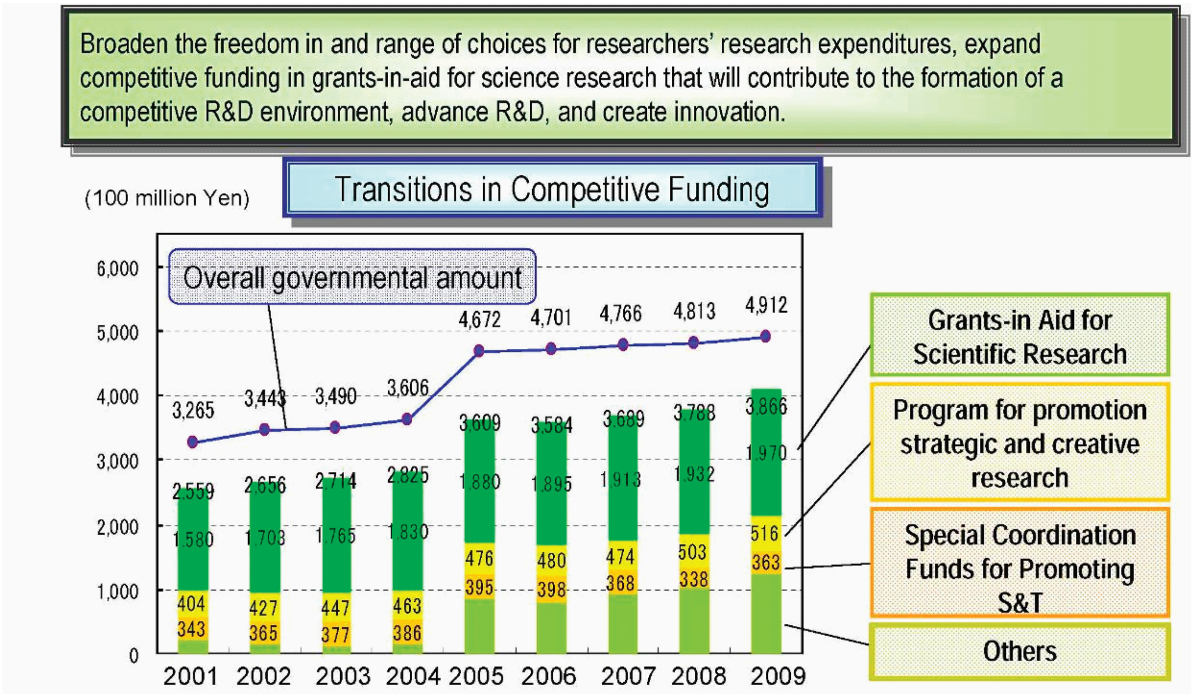

FIGURE 6-1 Expansion of research funding in Japan, 2001-2009.
SOURCE: Inutsuka (2009).

Increased Government Funding for R&D

The Japanese government prescribes its budget for supporting R&D in five-year periods. Despite the fiscal woes caused by its weak economy in the 1990s, Japan increased its ratio of government-funded research to GDP from 0.6 percent in the early 1990s to 0.69 percent in 2000. For comparison, the corresponding figures in 2004 are 0.83 percent in the United States and 0.76 percent in Germany. These figures include military R&D, which represent a larger fraction for the United States than for Japan. R&D spending increased by about 30 percent in 2005 (see Figure 6-1), and this new level has been maintained since then. The infusion of new funds allowed Japanese national universities and institutes to modernize their research facilities and to expand research activities in four specific areas, namely life sciences, information and communication, environment, and nanotechnology.

The combination of institutional reforms and increased funding for research has led to significant increases in the number and citations of papers published in major scientific journals. Between 1991 and 2004, Japan's share among highly cited papers increased by about 50 percent, from 7 percent in 1991 to 9 percent in 2001, and then to 10 percent in 2004.

University-Industry Partnerships

In the late 1960s and early 1970s, the strong research collaboration that had existed between Japan's national universities and its industry started to weaken, primarily due to the buildup of R&D capability in Japanese companies. Currently, Japan's universities account for just 46.5 percent of basic research. Recognizing the important role that research universities can and should play in the development of technological innovation, Japan enacted in 1999 *The Law on the Special Measures for Revitalizing Industrial Activities* to encourage the transfer of technology from universities to industry, particularly in the arena of science-based technologies.

The 1999 law allows grantees of government-supported research to retain ownership of intellectual property and associated patents derived from the research. Also, legislation was enacted to encourage and support universities to establish technology licensing organizations. Furthermore, to encourage research collaboration between and among its national universities, national research institutes, and industry, the Japanese government provided special funds for establishing Collaborative Research Centers at its national universities. It also supported the creation of startup research laboratories (technology incubators) to accelerate the technology transfer process.

All of these new policies have had a very significant impact on how universities now regard intellectual property. A particularly demonstrative metric is the number of annual domestic patent applications submitted by universities, which rose from 641 in 2001 to 8,527 by 2005.

Reform of the Patent System

Since the mid-1990s, Japanese policymakers have placed strong emphasis on reform of the patent system, reflecting their assessment that the stronger protection of intellectual property (IP) rights in the United States since the early 1980s fueled the emergence of world-leading industries in biotechnology and information technology and ultimately contributed to higher levels of U.S. productivity and GDP growth. Japan has taken major steps to strengthen IP protection, including the enactment of the *Basic Law on Intellectual Property* (2003), creation of an Intellectual Property High Court (2005), and promulgation of a series of action plans coordinated by the Prime Minister's Intellectual Property Policy Headquarters (beginning in 2002). However a 2009 report by the Office of U.S. Trade Representative was critical of Japan's patent application process and of the copyright protection afforded e-commerce and content-related industries (USTR, 2009).

Green Innovation

The ruling coalition headed by the Democratic Party of Japan (DPJ) has made "green growth" a cornerstone of its public policy agenda. The DPJ has committed to slash Japan's greenhouse gas emissions by 25 percent relative to 1990 levels by 2010, a major break from prior policies. The government has indicated that it will achieve its ambitious objectives in part through "green innovation," the application of R&D technological breakthrough, and development of new "green" energy and environmental industries. Key policy measures include:

- Promotion of renewable energy by expansion of electric power feed-in tariffs and other measures. (In November 2009, Japan introduced a feed-in tariff system to promote use of renewable energy in the electrical grid.)
- Conversion of buildings into "zero emission structures" through adoption of heat pumps, eco-housing technologies, thermotrophic glass windows, and other measures.
- Development of innovative technologies including next-generation automobiles, storage batteries, and improved thermal power plant efficiency.
- Promotion of investments aimed at realizing a "low carbon society" through "greening of the tax system, regulatory overhaul, and other measures" (Nakao, 2010).

These policies will reduce Japan's exposure to energy dependency and will help Japan become and remain a global leader in green science and technology.

Japan's National Security Concerns

Japan's most important national security concerns arise out of the threat of military confrontation in northeast Asia. North Korea, a hostile neighbor, has developed nuclear weapons and possesses ballistic missiles capable of hitting Japan within a few minutes from launch. Japan is periodically shaken by North Korean missiles, which overfly its territory or territorial waters. China is modernizing its military and asserting claims to nearby waters and seabed resources that conflict with those of Japan.

In addition, Japan recognizes a range of quasi-military or nonmilitary national security concerns, reflecting the nation's historical experience and recent world events (MOD, 2009). Earthquakes inflicted enormous destruction and loss of life in the 20th century. Japan experienced conditions of near-starvation in the years immediately after World War II and cannot produce enough food domestically to support its population. Japanese policymakers are highly sensitive to environmental degradation, which gave rise to a massive public backlash against government and industry in the 1960s. The energy shocks of the 1970s affected Japan more severely than other developed countries, reflecting Japan's complete dependency on imported oil. The attacks on the United States on September 11, 2001, deeply affected the Japanese public (many of whom refused to fly anywhere months after the attacks). The Ministry of Defense has indicated concerns over potential activity by individuals or small groups of terrorists operating in Japan's territory. Recent epidemics (SARS, avian flu, swine flu) have raised questions about preparedness of the nation's health infrastructure for a lethal pandemic or bio-terror attack. Piracy threatens maritime communications upon which Japan's economic survival depends. Access to raw materials, particularly in competition with China, is a chronic and growing challenge for Japanese industry. Japanese leaders are so concerned about the country's growing dependency on Chinese-produced rare-earth elements that some are reportedly discussing a rapprochement with mineral-rich North Korea, notwithstanding the political differences between the two countries. Climate change may be fostering destructive natural events to which Japan, as an island nation, is uniquely vulnerable, such as typhoons and tsunamis.

Role of Science and Technology in Addressing Security Concerns

A review of Japan's current S&T projects with regard to national security indicates that the government is not, by and large, seeking to address these concerns through the development of breakthrough or disruptive technologies. Its R&D projects overwhelmingly involve the development of defined pieces of equipment and systems with applications meeting performance parameters capable of addressing very specific security concerns—reconnaissance satellites, scanners, underwater exploration vessels, efficient manufacturing systems, synthetic alternatives to various raw materials, and similar items.

Military R&D

Japan relies heavily on the security relationship with the United States to address traditional military threats in northeast Asia. Japan cooperates closely with the United States on ballistic missile defense (BMD), and its current multilayered BMD incorporates U.S.-developed Patriot and Aegis interceptor missile systems. This special relationship has enabled Japan to access U.S. defense-related technologies through licensing and collaborations on defense R&D and production in which Japanese companies (the principal source of Japan's defense-related R&D) have emerged as world leaders in the design and manufacture of materials, components, and electronic subsystems, which are critical to advanced weapons systems. Despite Japan's comparatively limited defense-related procurement, Japanese firms' successful production of commercial technologies with potential defense applications (e.g., semiconductors, graphite fiber, optoelectronics, data processing, and telecommunications) has enabled them to meet military specifications for sophisticated defense systems with respect to performance, cost, reliability, and quality. Japan reportedly hopes to be able to produce its own BMD equipment. Japan currently licenses more U.S. defense technologies than any other country.

In 2008, Japan enacted a new Basic Law of Space, ending Japan's nominal embrace of the principle of the nonmilitary use of space. In the spring of 2009, Japan's Strategic Headquarters for Space Development, headed by the Prime Minister, released a five-year plan for space development, emphasizing that the space program would focus on R&D for defense as well as commercial and scientific purposes. The plan was supported by the Democratic Party of Japan, which was then in opposition but has subsequently come to power and head of a coalition government. The plan calls for the development of a "Satellite System for National Security," which is designed to improve Japan's early warning and information gathering capabilities. In 2009, the budget for space research was increased by about 10 percent over 2008 levels, with most of the increase being directed to projects with military or potential military applications such as IGS (information gathering satellites, the space-related component of BMD consisting of new-generation optical and radar-based satellites) and the so-called Quasi-Zenith Satellite System (which will provide highly accurate satellite positioning services covering 100 percent of Japan's territory). According to some observers the new Japanese satellite development effort is intended to give Japan an independent early warning capability with respect to ballistic missile launches that is not necessarily integrated with or dependent upon U.S. BMD systems.

PROJECTED ADVANCES IN S&T PROFICIENCY

Japan has demonstrated the ability to excel in innovation across a broad spectrum. Professor Shinya Yamanaka's research team at Kyoto University pioneered the cultivation of human-induced pluripotent stem cells, demonstrating the nation's ability to become a leader in biotechnology. Robotics and factory automation is an area in which Japan is and will remain a leader. The government has committed $100 million to the development of mobile personal care robots for eldercare, seen as a necessity given the aging population and the looming shortage of eldercare workers. Japan also leads the world in the deployment of systems of infrared and microwave sensors and radio transmitters along highways to alert vehicles of traffic hazards. In nanotechnology, a research team at Nagoya University reported in 2009 that it had created an "optical driven nano machine," a microbe-sized robot capable of moving individual human cells in response to commands (Sankei Shimbun, 2009). Yet another arena in which Japan is a leader, if not the world leader, is the development of microgrids, or localized groupings of electricity sources that can operate in connection with centralized grids but can also disconnect and operate autonomously.

Most of Japan's S&T plans for the future consist of short-term goals to be completed in five years or less. Goals aimed at specific tasks, such as refinement of a particular manufacturing process or development of a new generation of equipment, are generally met. Goals are not met as often in projects involving systems and systems integration (e.g., high-performance computing, operating systems, or aviation). This may reflect the fact that Japan has traditionally accorded higher prestige to hardware than to intangibles (software and systems). But most of Japan's security threats are complex, multifaceted concerns that cannot be met with simple technological fixes such as new kinds of robots and memory devices. Because a number of the security threats that Japan confronts are arguably best countered by complex systems (e.g., missile defense) it is unclear that the country's S&T efforts are equal to the challenges it faces. Japan will meet most of the goals it has defined for national R&D projects within three to five years, but many of these are directed at achieving refinements on existing technologies (e.g., three-dimensional semiconductors, spectroscopy, refinements of rice genomes) rather than at transformational breakthroughs.[2] Longer-term objectives tend to emphasize reform of Japan's science infrastructure (increasing internationalization, upgrading life sciences infrastructure), and if the past is a guide Japan is less likely to succeed here.

S&T INVESTMENTS OF INTEREST

In its third S&T Basic Plan (2006-2010), Japan defined four priority areas in S&T research, and another four "promotion areas" in which the research conducted by universities and national institutes is required to have close coordination with government agencies. The eight areas are described in Figure 6-2. Funding for the four priority areas has increased from 28 percent of the total R&D budget in 1991, to 42 percent in 2004, and to close to 50 percent in 2009.

Included in and in addition to the priority areas set forth in the third Basic Plan, three research areas stand out with regard to their potential impact on Japan's national security and future success as an S&T leader. They are (1) improvement in food security, (2) development of alternatives to rare-earth elements, and (3) satellite technologies.

Reacting to the memory of famine in 1945-1947, Japan is heavily invested in measures to improve food security. It may achieve significant breakthroughs in areas not researched as intensively in other countries, such as breeding of marine life, application of rice genome information to crop breeding, and use of microbes in fermentation processes supporting food production.

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[2]Breakthroughs have, however, occurred recently in Japan. One notable example is the identification of the four necessary ingredients to generate stem cells from adult cells (Okita et al., 2008).

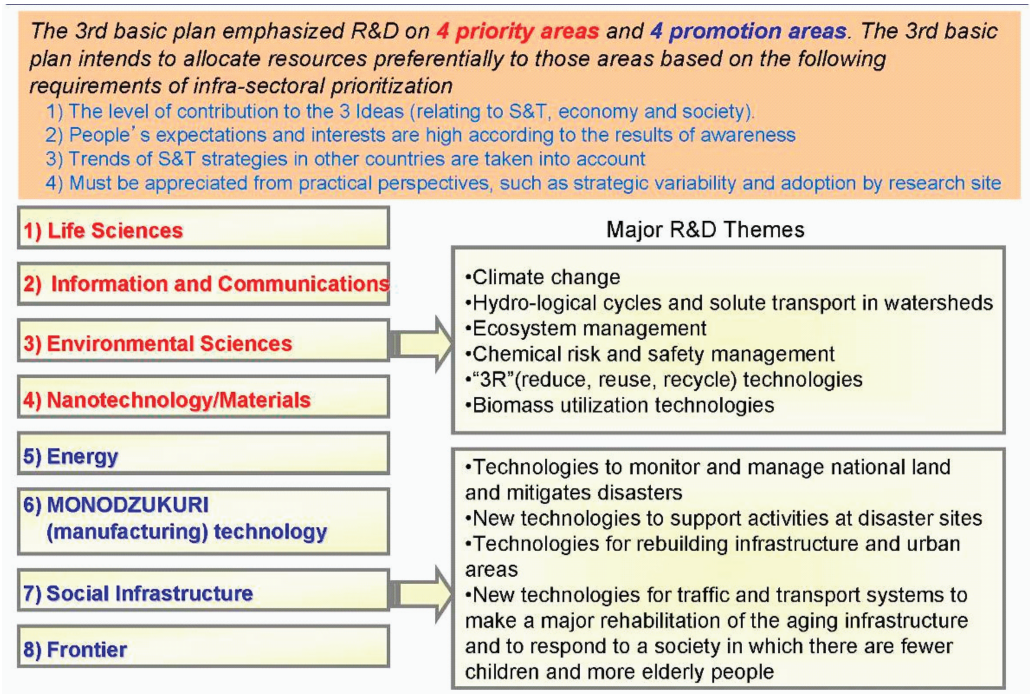


FIGURE 6-2 Priority and promotion areas.
SOURCE: Inutsuka (2009).

Japan is addressing the challenge posed by China's looming rare-earth-element monopoly by developing technological alternatives (such as production of electrodes without use of indium), which could avert a crisis in its manufacturing industries in the event that China withholds supply.

Improvements in Japan's satellite capabilities will have multiple effects on its security. In addition to countering the missile threat from North Korea, high-performance satellites could prove crucial in a military confrontation with China in which submarines threaten the sea lanes (Earth Observation and Ocean Exploration System). Satellites are instrumental to Japan's plans for developing seabed energy and mineral resources. Satellites and global positioning systems (GPS) will enable Japan to monitor all of its territory, although, as the U.S. experience in Afghanistan demonstrates, even very sophisticated systems of aerial surveillance cannot completely prevent infiltration by small groups of terrorists.

Japan's civilian research establishment is making substantial commitments to addressing unconventional threats to national security. The highest visibility efforts involve five "national critical technologies that concern consistence [sic] of Japan," listed in the Council for Science and Technology Policy's Strategy for Innovative Technology (CSTP, 2008). The five critical technologies as described in this document are as follows:

- **Faster Observation and Ocean Exploration System.** This system will use satellites and underwater vehicles to monitor the sea bottom's seismogenic zone and "submarine resources," which are believed to include hydrocarbons and rare-earth elements.
- **X-Ray Free Electron Laser.** This project will establish a facility for the development of "an ultra high-speed dynamic state oscillating x-ray laser with as bright as 1 billion times those existing and the alternation of chemical reactions are being aimed at for common use in 2012" (CSTP, 2008).
- **Fast Breeder Reactor Cycle Technology.** This project will seek to develop a reactor that produces more fuel than it consumes, "contributing to long-term energy security." (No cautions were provided about the increased security risks from this technology.)

- **Next-Generation Super Computer.** This project will seek to develop a "pioneering best global performance supercomputer." This goal follows earlier government-sponsored efforts to develop advanced computers that have fallen short of achieving their objectives.
- **Space Transportation System.** This project will focus on the development of rockets that are needed to preserve a domestic capability to launch "necessary artificial satellites into space independently when needed."

In addition to these five efforts, a recent report by Japan's Cabinet Office identifies a number of "innovative technologies" that have national security as well as economic and social dimensions. With respect to these innovative technologies, the government states, "It is very important for us to make some seeds of innovative technologies, to develop them rapidly, and to lead to society-wide innovation in the long term. This will necessitate a strategic program for research and development" (CSTP, 2008). The following R&D objectives have been identified:

- **Food Security and Health**
  —Development of inexpensive, portable "non-contact visualizing analysis devices" for food contamination checks, airport security checks, monitoring of environmental pollution, and quality checks on the manufacturing of medicines
  —Development of strains of rice, wheat, and soybeans that can thrive in poor environments and double current yields
  —Development of egg-laying control technology and surrogate womb technology to promote the breeding of eels and tuna, reversing the decline of seafood protein resources and "enriching Japanese food culture"
  —Development and production of an effective anti-malaria vaccine derived from plants

- **Resource Development**
  —Energy independence
  —Development of alternatives to rare-earth elements such as indium, dysprosium, and neodymium to reduce current vulnerability to Chinese monopolization
  —Development of renewable biomass materials as energy resources that do not compete with food production

- **Environment**
  —Development of a "new catalyst chemical manufacturing process technology," an underwater production process that would eliminate many chemical production byproducts, thereby reducing by 25 percent the waste byproducts of the chemical industry
  —Development of "global warming countermeasure technology" by establishing (a) hydrogen production technology that does not emit greenhouse gases and (b) high-efficiency photovoltaic power generation technology
  —Energy conservation
  —Development of superconducting materials technology with high current/magnetic field tolerance for application in magnetic levitation (such as high speed mass transportation)

Japan is the most energy-efficient country in the world, consuming less than half the energy per unit of GDP of the United States. Given its lack of petroleum resources, Japan has been forced to confront the need for energy conservation continuously since the onset of the first crisis in the early 1970s. It has developed a vast array of "green," energy-efficient technologies such as hybrid/electric vehicles, highly efficient water heaters and batteries, photovoltaic solar panels, highly efficient lighting, hydrogen fuel cells, thermotrophic glass, and "green" appliances such as waterless washing machines. With the world turning increasingly to alternatives to oil, vast infrastructural changes will be necessary in which Japan's green technologies and existing manufacturing capability with respect to green products are likely to be of critical importance.

NATION-SPECIFIC INDICATORS OF S&T ADVANCEMENT

When looking at possible indicators of S&T growth in Japan, it is perhaps most beneficial to focus on those related to the structural problems that have long acted as a drag on innovation, that is, the level of partnerships between universities and industry, amount of foreign investment, number of new businesses and startups, size of the domestic workforce, and women in the workforce.

University-Industry Partnerships

An examination of the number of university-industry joint research projects and the number of startup companies launched each year from universities reveals the extent to which Japan is overcoming the critical problem of isolation of universities from industry. National policies introduced over the past two decades to increase collaboration between universities and industry are starting to pay high dividends. The number of joint university-industry research centers at Japanese universities has increased from 3 in 1987 to 62 in 2002. The number of university-industry joint research projects has increased from about 1,400 in 1995 to more than 6,000 in 2003 (Figure 6-3).

The percentage of published papers that originated in Japan and were co-authored by individuals from industry and universities rose from 38 percent in 1991 to 54 percent in 2001. The number of startup companies spun off from universities increased from 14 in 1995 to 179 in 2003 (Figure 6-4).

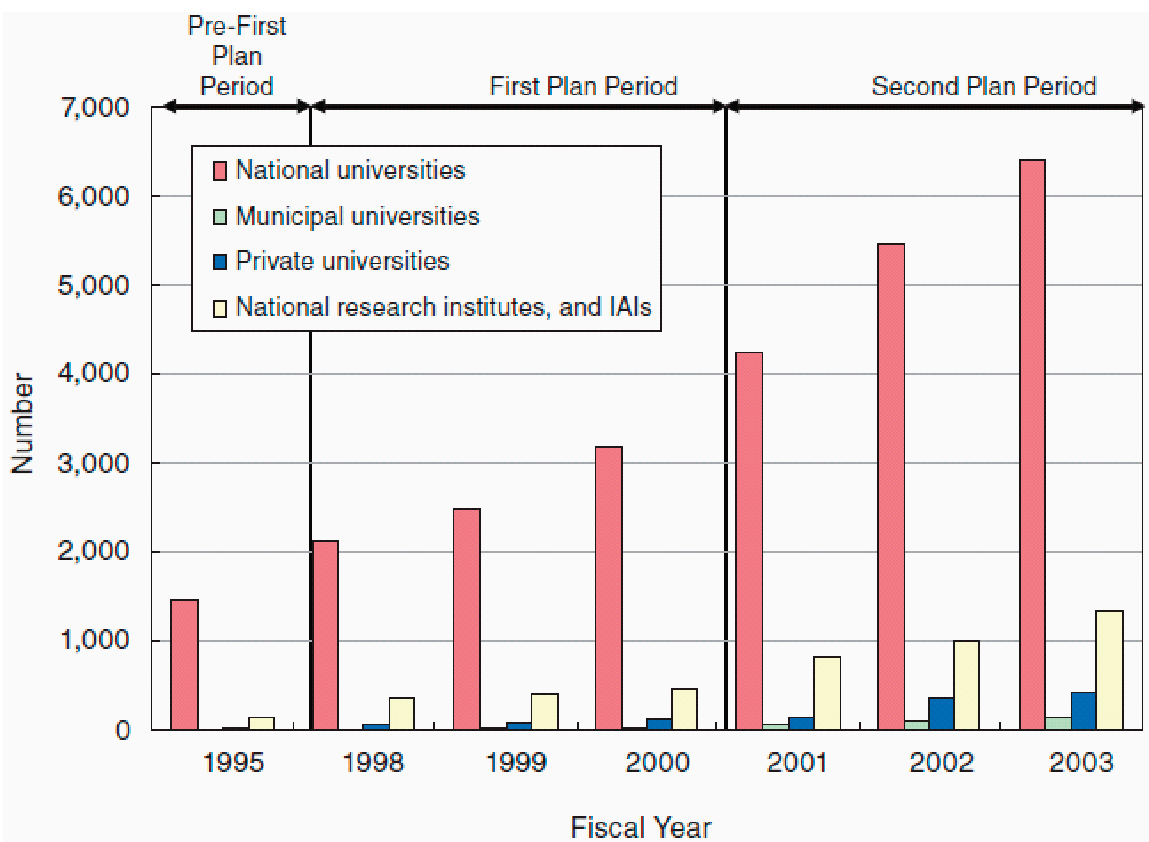
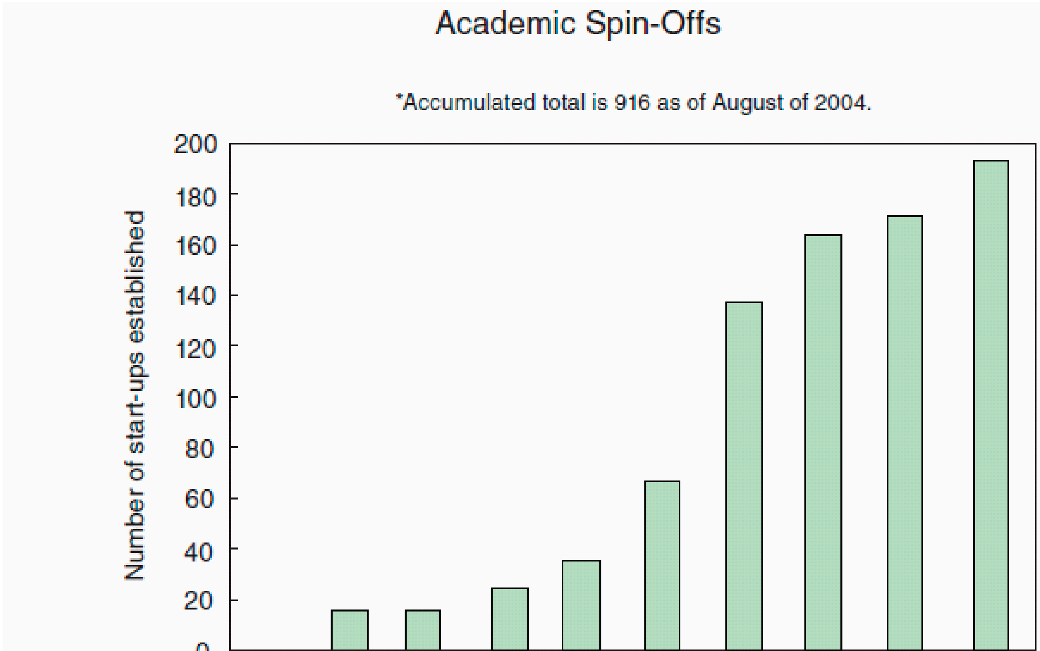


FIGURE 6-3 University-industry joint research.
SOURCE: NISTEP (2005).



	Up to 1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Number of start-ups annually established	38	14	15	22	33	62	127	152	159	179

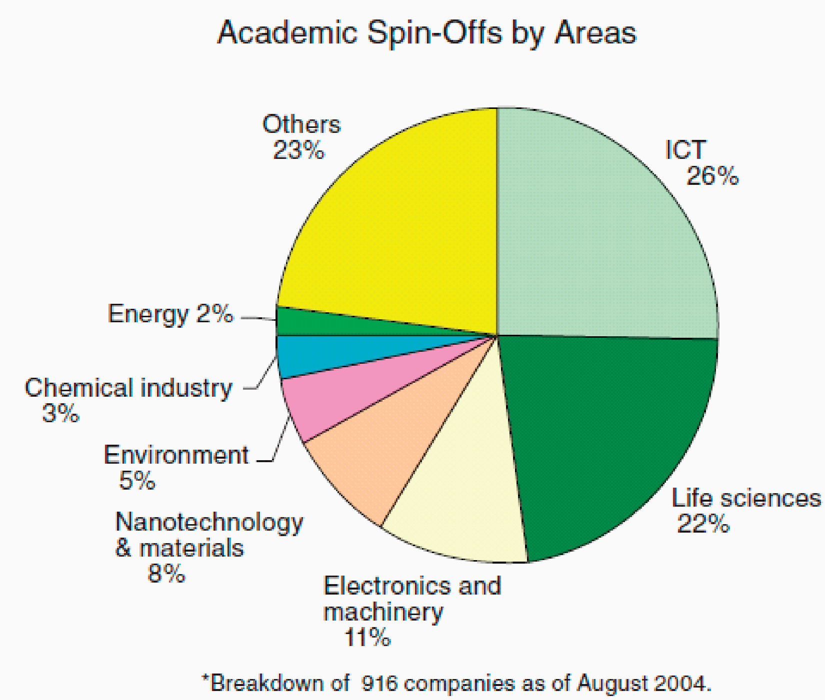


FIGURE 6-4 Academic spin-offs in Japan.
SOURCE: NISTEP (2005).

TABLE 6-1 Foreign Direct Investment Levels

Country	FDI as a Percentage of Nominal GDP (2003)
Japan	2.1
United States	37.5
United Kingdom	37.5
Germany	27.4
France	42.6
Canada	31.9
Australia	36.9

SOURCE: Adapted from MAC (2005), using IMF International Financial Statistics.

Foreign Direct Investment

Many of the most important technological breakthroughs of the past generation are attributable to the research efforts of multinational corporations. It is therefore significant that Japan has by far the lowest level of foreign direct investment (FDI) of any major developed country (MAC, 2005). See Table 6-1 for related statistics from the International Monetary Fund.

With some exceptions, technology-intensive multinationals do not undertake substantial levels of investment in Japan or conduct major collaborative research with Japanese firms. Although Japanese companies devote substantial resources of their own to developmental R&D, their comparative isolation from global commercial research efforts will continue to limit Japan's ability to emerge as a leading innovator. Japan's leaders have recognized this dynamic since the mid 1990s and have deployed an array of incentives to attract foreign investment, but with limited success (Koizumi, 2003). A significant increase in the level of FDI relative to other developed countries would be an indicator that this problem is being overcome.

Start-ups

Japan has not yet succeeded in creating an environment that encourages risk-taking by entrepreneurs and venture capitalists, a deficiency that continue to act as a drag on innovation. The Japanese government recognized in the 1990s that Japan's market entry rate for new businesses had been declining since the 1970s, "indicating stagnant entrepreneurship in Japan" (NRC, 2009). In 2009, Naoto Kan, Japan's current Prime Minister, who was then serving as Minister of State for Science and Technology, commented, "Unfortunately we do not yet have an environment in Japan that is suitable for venture companies" (Kato, 2009). Indeed, in 2007, U.S. venture capital investments were over 23 times the level of venture capital investments in Japan (METI, 2009). The government's response has been a series of measures to encourage entrepreneurship. Indicators that such policies are encouraging innovation would be an increase in the number of small- and medium-sized businesses holding proprietary self-developed IP and an increase in net revenue generated by companies that started out as small businesses with proprietary IP. A third indicator that has already been noted is the number of start-ups spun off from universities, which are increasing.

Social and Demographic Indicators

Japan has the highest proportion of citizens over the age of 65 and the lowest proportion of children under the age of 15 of any developed country in the world, raising the prospect that if present demographic trends continue, Japan's population could drop from 130 million in 2005 to under 50 million by the end of this century. The country already faces a shortage of skilled workers, exacerbated by low rates of immigration and a comparatively low participation in the workforce by women, who tend to enter the workforce when young but drop out thereafter. The working-age population of Japan is projected to drop from 81.64 million in 2009 to 73.63 million by 2020, and to fall below 50 million after 2050 (METI, 2010).

Increased reliance on robots and offshore manufacturing can partially offset the decline in the size of the workforce, but scientific research and innovation will inevitably suffer from growing shortages of personnel. It is unlikely that Japan's lack of receptivity to immigration will change over the near or medium term, and the country's ability to attract researchers from abroad is unimpressive. Japan's current government, a coalition headed by the DPJ is reportedly considering changes in the tax system that currently deter women from remaining in the work force (creating incentives for nonworking housewives). Indicators that Japan is succeeding in partially reversing adverse demographic trends would be an increase in the birth rate, a sharp increase in the number of women over 30 years of age with advanced degrees in the workforce, an increase in levels of immigration, and growth in the number of women and immigrants holding S&T-related jobs.

Patents

Japan is a leader in terms of the sheer number of patents issued; of the top 10 companies awarded patents in the United States, 6 are Japanese. However, this metric may not be a useful tool for benchmarking Japan's progress in innovation. The extent to which these patents are defensive in nature and not obtained for the purpose of appropriating returns from inventions is unclear. A proliferation of defensive patents could actually work as a deterrent to innovation—the so-called "patent thicket" problem.

FINDINGS AND RECOMMENDATIONS

Shaken by the economic stagnation that began after 1990, Japan's policymakers implemented a series of policy reforms designed to enhance innovation, drawing heavily on the example offered by the United States in areas such as IP protection, industry-university collaboration, start-ups, and industry-government R&D. However, it is too soon to assess whether these gradual reforms will bear fruit. Impediments to the attainment of innovation leadership include Japan's conservative business establishment, industry's relatively low level of participation in transnational R&D efforts, the inflexible career trajectories of Japanese researchers, and top-down innovation policies overemphasizing mega R&D projects by large domestic companies and government laboratories.

Finding 6-1. Japan has experienced an erosion of market position relative to other countries in a number of high-technology sectors. Japan is unlikely to reverse this relative decline in 5 years, and even 10 years may be optimistic.

Japan's S&T initiatives are likely to have a comparatively modest and incremental impact on the United States. It is unlikely that Japan will evolve into an adversary or direct security threat to the United States in the next generation. If the past is any guide Japan's defense-related S&T research will be of limited utility to the United States, and the coordination of bilateral R&D efforts will remain inadequate. Japan may develop specific national-security-related technologies that prove useful to the United States (such as vaccines, "clean" manufacturing processes, or synthetic alternatives to rare-earth elements). Japanese R&D projects may also enable Japanese companies to achieve competitive gains relative to U.S. firms in some industries, including strategic industries, as has occurred during the past 40 years. However, such developments will not destabilize the bilateral relationship or dramatically affect U.S. national security.

Finding 6-2. Reflecting its national experience, Japan has focused its S&T to address specific nonmilitary threats that could very well confront the United States in the future in areas such as energy, food security, natural resource availability, and environmental degradation.

Recommendation 6-1. The United States should position itself to capture value from Japan's R&D efforts in niche areas involving energy, food and resource security, and environmental protection.

Finding 6-3. Japanese industry, like U.S. industry, is experiencing pressure from China to transfer proprietary technologies.

Recommendation 6-2. Countries creating S&T innovation enterprises should collectively address China's pressure to transfer proprietary technology.

Finding 6-4. Japan's ability to achieve its S&T goals may be impaired by demographics and weaknesses in its S&T infrastructure. However, it is in the interest of the United States that Japan's reform efforts prove successful.

Recommendation 6-3. The United States should work to build and deepen relations with Japan across the entire policy spectrum. In S&T this would include joint R&D, university exchanges, and technology-sharing arrangements.

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Chapter 7

Russia

Russia is a physically expansive country with great resource wealth, high regard for education, and high levels of achievement in basic science. However, it struggles with an aging and declining population, a high level of corruption in both governmental and industrial sectors, and most damaging, a culture that does not encourage the translation of its strong basic research capacity into globally competitive commercial products. The government is attempting to address this last problem by recruiting foreign talent and investment, facilitating trade, and encouraging entrepreneurship, but it is likely to be unsuccessful because its programs do not target the fundamental cultural changes that are required. However, Russia will continue to do well in those areas that benefit from a centralized, top-down approach and in which Russia has traditionally been strong, such as materials extraction, space, and nuclear development.

INTRODUCTION

Although it is generally true that any country's science and technology (S&T) strategy has to be viewed in the context of its specific circumstances, this seems to be especially instructive for Russia. Geographically, Russia is the largest country in the world, measuring 17.1 million square kilometers, and spans 11 time zones. Despite its enormous land size, Russia's population is only about 140.3 million (2009), with almost 80 percent of its population living in Western Russia. Two-thirds of the population resides in cities (Curtis, 1996). Although the breakup of the Soviet Union occurred along national territories, the Russian federation is very multicultural with more than 100 distinct national minorities. Providing the appropriate infrastructure (e.g., transportation, communication, healthcare, government services, economic support) while dealing with urbanization and developing the remote regions of the country (where much of Russia's natural resources are located) is of great importance to national development.

The Russian population has been declining for quite some time (decreasing by 0.5 percent in 2009, one of highest rates of population decline in the world). Approximately 23 percent of Russian citizens are above 65 years old, and almost one-quarter of the population is on a pension (ING, 2003). This reality has many longer-term social, political, and economic consequences, but it also highlights the immediate challenges for the country's healthcare system and places a mounting financial burden on younger generations.

Russian politicians often refer to their political system as a "sovereign democracy," not only to differentiate it from traditional Western democracies but also to disguise the fact that political power is in the hands of a very few

(Kuchins, 2006). Although it can be debated whether or not Russia's political ambitions are imperial (Applebaum, 2008; Shevarnadze, 2009), it is generally clear that Russia is seeking to restore its past role as a major geopolitical force. One very important feature of this strategy is for Russia to become a global energy supplier, or "energy superpower." Russia is eager to control the Western energy supply and leverage that power as a bargaining chip to advance national interests (HJS, 2008; Mityaev, 2009). This stance was recently made evident when it was reported that the leader of a Russian expedition to the Arctic claimed extensive rights to parts of the North Pole with major implications for the exploitation of energy resources (Zarakhovich, 2007). Although Moscow later distanced itself from these territorial claims, the fact that the Russians successfully completed a submersible journey at 14,000 feet beneath the Arctic ice emphasizes Russia's determination and technical capabilities. The goal of becoming an energy superpower is also supported by Russia's ambitious plans for a massive expansion of its nuclear power industry (Daly, 2009).

The Russian economy grew an average of more than 7 percent annually between 1998 and 2008 (Curtis, 1996). However, most of Russia's recent economic success has been based on an excessive exploitation of its rich natural resources (e.g., oil and gas). Russia has more proven natural gas reserves than any other country, and it is the second largest oil exporter in the world (CRS, 2007). However, dependence on these commodity resources has in turn made Russia highly dependent on global prices (EIA, 2008). Most of Russia's proven oil reserves are located in very remote regions such as Western Siberia, between the Ural Mountains and the Central Siberian Plateau, as well as on Sakhalin Island in the far eastern region of the country. Transportation of energy and the relatively high cost of energy production, exacerbated by aging and outdated infrastructure, present significant challenges. Russia has failed to become competitive in sectors of the economy that extend beyond the export of primary goods, such as the manufacturing sector. For example, productivity in manufacturing is only 50 percent of that of Poland and 40 percent of that of Brazil (Goldberg and Desai, 2006).

Other important factors hindering Russia's economic progress are corruption, bureaucracy, and the lack of political transparency. All of these have a paralyzing effect on private and especially foreign investments. In almost any survey assessing fraud and political bribery, Russia can be found on the top of the list (PWC, 2009). In the most recent report by the World Trade Organization on global competitiveness, Russia was ranked 63rd out of 133 countries (World Economic Forum, 2009). Russia has the lowest score on global competitiveness among the BRIC countries (Brazil, Russia, India, and China) and fares especially badly on transparency of government policymaking and the burden of governmental regulation. Significant problems also exist with regard to property rights, real estate transactions, and land privatization.

Russia inherited a high-quality education system from the Soviet Union. Despite growing challenges since the breakup of the Soviet empire, the system has remained very good, producing a literacy rate of 99 percent (Data360, 2006). Education—especially higher education—is highly valued in Russian society (Eklof, 1996; MES, 2004). The Russian constitution grants the right to free basic education but access is provided on a competitive basis. More than 50 percent of the Russian population has a higher education, compared with 24 percent of the American population (Bauman and Graf, 2003).

Russian higher education is offered in three different ways (Johnstone, 2008). Universities (e.g., Moscow State University, Saint Petersburg State University, Moscow Institute of Physics and Technology, and Rostov State University) cover the broadest spectrum of disciplines, combining undergraduate and graduate teaching and research. Academies focus on a few selective branches of science (e.g., Academy of Mining, Academy of Architecture, Academy of Arts, and Academy of Sciences). Finally, institutes, which can be independent but are generally publicly owned, offer several professional education and selective research programs. Historically, the bulk of S&T research in Russia is conducted by the academies and institutes with minor research work at universities, which is in stark contrast with the U.S. system where the best researchers are not shielded from the "bubbling fervor of undergraduates" (Graham, 2010). Russia has a long and distinguished history in basic science. It has gained a global reputation with institutions such as the Russian Academy of Sciences and prides itself of its Nobel laureates in the sciences, especially in physics. Russia scores very well on certain Organisation of Economic Co-operation and Development (OECD) metrics (such as quality of its scientific research institutions, numbers of researchers, or numbers of science and engineering degrees), but it does very poorly on metrics of innovation output (INSEAD, 2009; IBM, 2009). Some of the reasons for this low rate of conversion of basic science to innovative technologies and products can be understood from the recent history of Russian S&T.

After the fall of the Soviet Union, Russian science encountered significant challenges. First, because of the easing of emigration and travel restrictions, many Russian scientists left the country, and this brain drain continues today. By 2002 it was reported that more than 500,000 scientists had left Russia (BBC, 2002). This trend includes in particular the most gifted, often middle-age scientists at the peak of their scientific productivity. This emigration not only causes substantial economic damage but also contributes to the aging of S&T personnel in an already aging society. Naturally, the more established, older S&T personnel are more likely to be rooted in the past traditions of the Russian S&T system, and they often oppose the necessary reforms that have occurred in other countries. Second, after the fall of the Soviet Union, Russia's budget for science shrank, becoming three to four times smaller in 1992 than it had been in 1990 (Saltykov, 2007). Throughout the 1990s, many S&T institutions lost basic research capabilities (Graham, 2003; Goldberg, 2005). Finally, the central S&T planning approach of the Soviets, with clear thematic priorities for national security and military applications, had served as an effective framework and guide for Russian scientists. By contrast, the early days of the Russian Federation lacked larger thematic priorities, and until today S&T activities have been fragmented, not aligned to priority subjects, and have included little interaction between the S&T institutions.

Until very recently, S&T research was mostly conducted by publicly owned R&D institutions. The support for these institutions came mostly from "block funding," which was the result of centrally made planning decisions. Little accountability was attached to these block funds, which were often handed out based on political influence. Competitive funding mechanisms, either through public-private partnerships or venture capital, were not available. During the Soviet era, application and transfer of S&T knowledge was part of a larger plan, which was driven solely by the central government. Without the government as a customer, there is no incentive for Russian scientists to drive basic research into innovative solutions and products. The lack of an entrepreneurial tradition has resulted in an S&T system that is very weak in commercializing new technology products.

The concept of intellectual property (IP) rights for individuals or non-public entities has little tradition in Russia. Often assignment of IP rights is not transparent; specifically, it is unclear if the IP belongs to an individual inventor, an employer, or a government R&D sponsor. Naturally, these uncertainties have hindered effective collaboration between private firms and public institutes, inhibited technology transfer, and severely impaired the generation of spinoff companies.

Russia is the largest country in the world, but its research policies and strategies still are predominately shaped and implemented at the federal level, with the Ministry of Education and Science playing the main role and the primary regional governments playing a minor role. However, the president, government, and legislature have recently founded new organizations that support the S&T priorities, underlining the fact that S&T strategy has gained special attention in Russia.

Modernization of State-Owned Industries

It is clear that major changes in the innovation ecosystem are required to modernize the inefficient state-owned enterprises. In fact, the public-sector share in Russia has never fallen below 40 percent, and during the recent financial crisis, it has increased. The Russian president stated in his November 12, 2009, address to the Russian Assembly that "this legal form of enterprise has no future overall in the modern world" (Medvedev, 2009c); he declared that by 2012 there will be a plan for determining an optimum level of participation by the government in the operation of commercial business.

The lack of activity in high-technology sectors, such as nanotechnology, by the private sector needs to be addressed. One approach is to organize a system of state orders for long-term procurement of innovative products. Other ideas include creating a "green corridor" or special trade arrangement to facilitate the export of hi-tech products, as well as instituting more favorable customs clearance procedures.

In November 2009 the president issued instructions for the prime minister to submit proposals to deal with reforming and privatizing state corporations (Medvedev, 2009c). These proposals, which the president asserted should turn state companies into "organizations with a different organizational and legal status" and should have "legislative guarantees of the transparency of their activities," were expected to be submitted by March 1, 2010 (Medvedev, 2009d).

Improved R&D Environment

Recently, Russia has been improving the basic elements of its innovative infrastructure through the development of the following (APEC, 2008):

- 55 technological parks
- 66 innovative-technological centers (ITCs)
- 80 business incubators
- 86 centers for technologies transfer
- 10 national information-analytical centers, that is, digital libraries (NIACs)

These efforts are to be further enhanced through a variety of measures directly targeted at improving the financial and human capital involved in innovation. In fact, a deadline of the first quarter of 2010 has been set for the government to make the organizational and financial decisions needed to attract foreign scientists and to increase new technology funding.

Of particular interest are foreign scientists and entrepreneurs with experience in commercializing new developments. To attract them, Russia would relax the rules for hiring these foreign specialists and for recognizing degrees and diplomas awarded by the world's leading universities. In addition, visa requirements would be modified so that they can be obtained quickly and will allow long-term residence.

An immediate increase in grants is also planned for researchers who are creating new technology through development institutes. The grants will fund projects from throughout the country in collaboration with university-based incubators and private investors. In addition, major companies are being encouraged to fund research that will undergo an international expert evaluation and be carried out in partnership with foreign centers and industry.

To facilitate investment, an immediate deadline of January 2010 was given to the regional authorities to draw up proposals for new procedures for obtaining the approvals and permits needed to launch projects. The goal was to reduce the time to begin a new effort to 3 to 4 months from the current window of 18 to 24 months. Another supportive change was the introduction of laws establishing favorable conditions for innovative activity, including, but not limited to, the introduction of a five-year transition period limiting mandatory social insurance contributions.

"New Schools" Initiative

An initiative, which was called for by the president in 2008, has been drafted and has the high-level goal of providing an education system that addresses high-technology requirements. In addition, 2010 has been declared the "Year of the Teacher," which indicates a national interest in improving and extending technical education (Medvedev, 2008).

Projects that will be implemented countrywide starting in 2011 involve the construction of new "smart" buildings with broadband Internet. New standards for physical education, nutrition, and support for those with disabilities will be included in these projects. Other reforms involve giving independence to high-performing schools and ensuring educational parity in remote areas through such techniques as distance learning and improved teacher training and certification.

Military Infrastructure

Military investments in Russia are now moderate compared to Soviet-era levels. Nevertheless, by 2010 the transition of Russia's armed forces to a "modern, efficient and mobile" army should be complete. Key among these improvements is rearmament with advanced military equipment. Weapons that will be acquired in 2010 include more than 30 ballistic land- and sea-based missiles, 5 Iskander missile systems, about 300 modern armored vehicles, 30 helicopters, 28 combat aircraft, 3 nuclear-powered submarines, 1 corvette-class battleship, and 11 spacecraft. Also there will be a focus on improving the logistics of supplying and supporting these advanced arms.

Before 2012, modern automated control centers and information systems will be in place, which will replace outdated analog communications equipment with digital systems. Equipping the troops of the North Caucasus Military District with updated communications equipment is a priority.

Three new major military training centers are now being installed in Moscow, the greater Moscow Region, and Saint Petersburg. Seven presidential cadet schools will follow, one in the Volga Federal District and others opening through 2012, with the goal of providing the military with professional sergeants and highly qualified junior command personnel.

The Russian Ministry of Defense and other law enforcement agencies are responsible for the construction and purchase of apartments for their personnel, which include providing permanent housing in 2010 and service housing by 2012. Funds for military housing and pay with material incentives were increased by more than 1.5 times in 2009.

NET ASSESSMENT OF S&T INVESTMENT STRATEGY

Russian S&T planning processes and investment strategies are top-down and highly centralized with political leaders playing a dominant role. Russia's strategies attempt to address the current weaknesses of the Russian S&T system, which include:

- lack of entrepreneurship and experience in transferring basic research into innovative technologies and products
- the overwhelming dominance of government S&T funding
- obsolete (and often corrupt) top-down funding mechanisms
- an insufficient system of IP rights to encourage entrepreneurship
- an outdated higher education system with little research at universities
- emigration of young talent, further exacerbated by Russia's population decline, resulting in an aging S&T establishment that will resist culture change

Generally the strategies can be characterized as addressing the symptoms of Russian S&T weaknesses but not the root cause, which results when the federal government, with is self-defeating central planning approach, becomes over involved and consequently undercuts reforms by preventing more competition and entrepreneurship. Russia is not likely to be successful in its efforts to modernize through high-technology investment and to move the S&T culture toward one that fosters interaction between research and industry and participation of private commercial entities. However, in certain areas such as energy, nuclear, space and aircraft systems, which typically require large national investments, Russia's current process is expected to be more effective. Advances in these areas will directly help Russia to expand its role as an energy superpower and major energy provider.

A long-range planning document developed in 2006 and titled "Long-term Prognosis for the Development of S&T in the Russian Federation Till 2025" included the short-term (2-year), mid-term (5-year), and long-term (15-year) goals discussed below (ISTOK, 2008; Zashev, 2010).

Short-Term Goals—2012

These goals were even more specific for innovation-based economic activity, with targets for such items as revenue ($5.5 billion) and numbers of competitive technologies (127-136) and experts (20,00-23,500). Even the amount of innovation was dictated, with goals for such benchmarks as the number of new critical technologies in which the Russian Federation has global priority (5-8).

Mid-Term Goals—2015

The mid-term goals were directed less to focus areas and more to increasing various generic metrics, such as the gross expenditure on R&D (GERD), the number of younger scientists, the amount of investment, and the number of patents. The overriding goal is to increase the number of "innovation" companies and the relative share of innovation products in the total sales volume of domestic production to 18 percent and exports to 15 percent by 2016.

Long-Term Goals—2025

These goals include the following:

- Using S&T to improve defense and national security, to modernize education, healthcare, transportation, and the agro-cultural sector, and to rationally use environmental resources
- Leveraging S&T to help Russia expand its leading role as an energy superpower and sole energy provider (nuclear, pipelines, energy infrastructure, etc.) (ISTOK, 2008; Zashev, 2010)
- Using Russia's well-developed research base to diversify the Russian economy beyond primary goods export (nanotechnologies, nuclear power, space and rockets, civil aircraft)

PROJECTED ADVANCES IN S&T PROFICIENCY

Generally, given Russia's present political situation and top-down S&T innovation strategy, it is very unlikely that Russia will attain significant global leadership in new advanced technologies. In the absence of major reforms that fundamentally transform the Russian S&T culture, it is projected that Russia will continue to lose ground over the next decade and beyond. However, Russia is expected to stay competitive in a few selected areas such as energy systems and energy distribution technologies, including pipeline construction; nuclear power, including both fission and fusion; and space, rocket, and aircraft systems. The nature of these areas is such that central planning and large-scale government investment is advantageous. Furthermore, Russia is already strong in these areas, and in some cases has a natural advantage because of its resource supply.

In spite of these strengths, significant advances in new high-technology areas such as nanotechnology, life sciences, and information technology systems are less likely to occur. Experiences in other countries have shown that these technologies require the intense participation of private enterprise to provide the diversity and experience necessary to develop and determine the technologies that will ultimately have large impact. Due to the lack of an entrepreneurial tradition, Russian research institutions and government do not have the proper incentives and motivations to be able to identify the technology paths that will lead to the ultimate "winners" in the global marketplace.

For Russia to be successful, its government must fundamentally change the national S&T system, which would include decentralizing the S&T strategic decisionmaking and funding processes. An additional missing component of the current strategy is an effective plan for more international openness, collaboration, and personnel exchanges.

The committee's analysis has shown that Russia's strategy serves the following three objectives:

- Leverage S&T to help Russia expand its leading role as an energy superpower and sole energy provider (nuclear, pipelines, energy infrastructure, etc.)
- Use S&T to improve defense and national security and to modernize education, healthcare, transportation and the agricultural sector, and to rationally use environmental resources
- Use Russia's well-developed basic research base to diversify the Russian economy beyond primary goods export

It is quite conceivable that within 10 years Russia will achieve the first goal and part of the second as it relates to the aforementioned large-scale projects. However, without a substantial change in its current strategy, it seems unlikely that Russia will be able to diversify its economy and modernize the country, which could have more serious consequences as it relates to U.S. strategic interests.

This negative situation could be further exacerbated by national budget shortfalls resulting from the global financial slowdown, which while particularly damaging to the nascent high-technology efforts will also affect the large-scale investment programs. For example, the Russian government recently had to cut R&D expenditures for its short-term programs by up to 30 percent of the initially planned allocations.

S&T INVESTMENTS OF INTEREST

Russia seeks to leverage its traditional strength in basic research and strong research institutions, and to diversify its economy beyond the export of primary goods. Even though these goals are supported at the top levels of the political hierarchy, it is expected that few developments in new high-technology areas, such as nanotechnology, will have global impact. However, those areas in which Russia has a natural advantage or historical leadership will continue to be important:

- Space systems and rocket technology for satellites used in global telecommunications
- Mining and extractive material-related technologies
- Petroleum extraction and pipeline distribution

One promising sign for the future of Russia is that top politicians have seen the need to rejuvenate and support S&T talent and to encourage a new culture within Russian research institutions. This is critical for Russia in the face of an overall declining population and a tradition of isolating the academies from commercial applications of their research. Recent measures include an increased investment in the research university infrastructure, which is hoped will entice young Russian scientists to seek education and careers at home. Changes in immigration and visa requirements have been implemented to facilitate the residence of foreign researchers, and new incentives exist for universities and academies to engage with private enterprise. If successful, reform coupled with mobilization of the highly educated Russian population could be the foundation for a future renaissance in Russian S&T.

Five priorities for the Russian Federation were clearly enunciated by President Medvedev in his November 2009 Presidential Address to the Federal Assembly and later supported by Prime Minister Putin (Medvedev 2009a,c,d; TI, 2010). The fact that the two top leaders appear to agree on these S&T priorities gives credibility to this plan as an official direction for the Russian S&T environment.

The five focus areas are as follows:

- Medical technology, medical equipment, and pharmaceuticals
- Energy efficiency, conservation, generation, and distribution
- Applications of nuclear fission and fusion
- Telecommunications and space technology
- Computer and information technology

Related information about these focus areas and others from government actions, documents, and presentations beyond the prime minister's and president's speeches and articles are described in detail below.

Medical Technology, Medical Equipment, and Pharmaceuticals

Health care technology is designated as the area of top importance in large part because of Russia's population decline. The healthcare initiative is a broad-based effort meant both to provide affordable quality treatment and to develop advanced technology for preventing and treating the most dangerous diseases.

Russia plans to produce more than 50 strategically important medicines, including the most expensive or frequently used treatments, with a particular focus on cardiovascular diseases and cancer. To address domestic market issues, a dramatic increase has been promised in the local production of pharmaceuticals to treat the most common illnesses such as influenza and the common cold.

Russia's first priority appears to be the health of its people. However, Russia also hopes to become a significant supplier in the global market, which will be accomplished in part by developing partnerships with leading foreign developers and producers. As a byproduct of such partnerships, Russia will build its capacity to advance medical research by itself.

Capitalizing on existing procurement mechanisms, Russia expects that local production will supply at least a quarter of the domestic market within five years, expanding to more than half by 2020. A draft law has already been sent to the State Duma, which releases regulations for the supply, sale, and safety controls for medicines.

Energy Efficiency, Generation, and Distribution

Russian citizens are being called upon to take more responsibility for saving energy. Other measures that have been discussed for reducing energy consumption include the installation of individual meters, transition to energy-saving bulbs, and a change in the payment system to reflect consumption and income levels (made possible by the individual-use meters). This initiative is similar to projects envisioned in the United States, in which energy consumption will be managed using "smart" meters. There is also a call for rapid action to stop the waste of natural gas, which is released during oil extraction.

Russian scientific research and production organizations have been called upon to develop innovative technology that will allow the use of bio-resources such as timber, peat, and industrial waste for energy production. Interestingly, the use of alternative sources such as photovoltaics, fuel cells, and wind power are not mentioned.

In a country as large as Russia (or the United States), the transmission of energy to population centers is a major issue. One particularly innovative technology considered by Russia involves the exploitation of superconductor technology to provide long-distance, low-loss power transmission. A program similar to this is currently underway in Western Europe (Jha, 2008).

Applications of Nuclear Fission and Fusion

There is a major focus on the use of nuclear energy as another part of the solution to Russia's future energy needs as well as an additional product to be sold into foreign markets. Russia has established the goal of developing next-generation reactors and nuclear fuel by 2014. Innovations in the nuclear field will also be applied in other areas, including hydrogen fuel, propellant devices capable of inter-planetary space flights, and medical technology. The President has stated that he believes that the real future of energy is in the exploitation of thermonuclear fusion and has expressed interest in working with other countries involved in the development of this technology (Medvedev, 2009c).

Telecommunications and Space Technology

Russia's communication infrastructure has suffered significant degradation, to the extent that Russia is now well behind the rest of the industrialized world. To remedy this situation, Russia plans to establish national broadband Internet access over the next five years through the use of a nationwide fiber optic network. This is quite a commitment given Russia's land mass and number of rural settlements. The most remote areas (e.g., Siberia and the Far East) will receive a pricing subsidy. In addition, the Russian government plans to transition to digital television and fourth-generation mobile phone communications—which means skipping over the third-generation mobile phone technology now used in most of the rest of the world. In addition to expanding broadband and mobile phone access, Russia plans to develop a unified emergency service, which works across all communication resources and is fully connected to the global communication infrastructure.

One important application of space technology is the upgrading of the GLONASS system, a radio-based satellite navigation system, which is now operated by the Russian Space Forces. Since it was completed in 1995, this unique system has fallen into disrepair, and a substantially different approach is now being developed, which will be compatible with the United States' global positioning system and the European Union's Galileo system.

A new "social GLONASS project," called Emergency Reaction to Accidents (ERA), is under development and will extend the use of the navigation system to a number of emergency response applications (Blinkova, 2009). This will include use in car navigation, transport safety, security, and digital mapping and will improve coordination in natural and man-induced disaster relief.

Plans call for a new generation of spacecraft to be developed by 2015, which will enable Russia to have worldwide reconnaissance and state-of-the-art telecommunication satellites. Russia expects to offer these capabilities to foreign countries for scientific research and for extending existing worldwide communications networks.

Computer and Information Technology

Russia plans to develop networks of supercomputers within five years to use in the design and simulation of new planes and spacecraft, cars, and nuclear reactors. A modern technological center, similar to Silicon Valley, will offer attractive working conditions for leading researchers, engineers, designers, software programmers, managers, and financial specialists.

Systems that provide Russian state services over the Internet are in development, and within two years more than 60 key state services will be electronically accessible. A pilot project will provide citizens with a "social card" for access to state services and medical and social insurance programs. In addition, Russia plans to combine these cards with electronic cards that provide access to banking services, which will be useful for making both obligatory and voluntary payments. It is hoped that this technology will combat the widespread corruption in Russia today.

In the meantime, an "Electronic Government" project due to launch in 2010 will allow Russians to access 300 federal services on one Internet portal. This includes applications for passports, social aid, treatment and recreation documents, and pensions. It will also contain data about transport, land, and property taxes of citizens as well as traffic fines. The director of this effort claims that the first socially important part of the effort has been implemented and now the focus is to ensure consolidation of regional, federal, and sectoral data (Tatar-inform, 2009). Another example of this project is the involvement of IBM to overhaul the Russian railways infrastructure using information technology (Upson, 2010).

Nanotechnology to Support Priority Areas

The Russian president has made it clear that nanotechnology is one of the major program thrusts that will support the five priorities (Ioffe, 2009; Medvedev, 2009b; Mokhoff, 2009). According to his estimates, there is a global nanotechnology market on the order of $250 billion, growing to $2 trillion to $3 trillion by 2015.

President Medvedev claims that Russia has the largest public investment program in the field of nanotechnology, which by 2015 will have allocated $1.1 billion for these purposes. He emphasizes the public nature of the investment, because it is well below the level of private investment in many countries. In fact, investment by the Russian private sector in nanotechnology is quite small at only $150 million. However, the president believes that by 2015, total sales by Russia's nanotechnology industry can be expected to reach about $30 billion, and a quarter of this amount will be the result of exports.

Rosnanotech, a state-owned and -funded venture capital fund, was formed in 2007 with a budget of $5.5 billion to facilitate growth in nanotechnology innovation. Scientists with a nanotechnology-related proposal apply to the company, and a panel of international experts selects projects for funding. Rosnanotech then acquires a minority stake with a goal of $8.5 million in sales by the fifth year and provides assistance in finding private investors and properly structuring debt, with the plan of an early exit. Public funding for Rosnanotech is set to expire by 2015.

An important component of the president's nanotechnology plan is to learn from and work with foreign companies. Craig Barrett of Intel Corporation signed an agreement with Rosnanotech in June 2008 to conduct joint research in several nanotechnology areas, including the development of new materials for the production of sub-45 nanometer integrated circuits (ICs). Additionally, Intel and Rosnanotech plan to collaborate on research in multiprocessor and multicore systems, as well as in software for modeling nanomaterials. Training in management and technology commercialization are also part of this agreement. Although this is clearly an important development for Russian S&T, it is uncertain that the results of this research will have an impact on new Russian commercial products. The primary focus appears to be on advanced IT manufacturing, an area in which Russia has had no significant past involvement. Because of the costs involved in setting up such a capability (a single production line now costs more than $1 billion), it is unlikely that Russia will develop a significant role in this sector.

NATION-SPECIFIC INDICATORS OF S&T ADVANCEMENT

To understand Russia's progress in S&T beyond the short term, there should be careful monitoring of the amount of nongovernmental funding, the level of foreign investments, the education and age profile of Russian S&T personnel, and the entry of Russian products into international markets.

Demographic data about Russian S&T researchers, such as age and education distributions and the numbers working in design and engineering versus basic research, are the most important indicators of progress in potential S&T. Additionally, to evaluate research conditions, the number of foreign researchers in Russia and the number of Russian researchers leaving permanently should be tracked.

Population decline is one of the most damaging indicators of Russian living conditions, and it should be carefully monitored using statistics that go beyond those that are given for political expediency.

The growing percentage of energy exports from Russia clearly indicates that it is making progress toward its goal of becoming an energy superpower. Crucial to this effort is the installation and control of pipelines and related energy distribution systems.

Russia's S&T prospects might be more uncertain than those of other countries discussed in this report. On the one hand, under the strict Soviet rule, Russian scientists have shown that they can develop complex technologies such as sophisticated (nuclear) weapon systems and can lead in space technologies. Their ranks include world-famous physicists and mathematicians and Nobel Prize winners. On the other hand, Russia suffers from a weak innovation environment, a situation which has drastically worsened since the fall of the Soviet Union. Today's problems include a weakness in translating basic research into innovative technologies, the overwhelming dominance of the government with few advanced S&T activities in private enterprise, obsolete (and often corrupt) top-down funding mechanisms, an insufficient system of IP rights, an outdated higher education system with little research at universities, and the significant emigration of young talent, leaving an aging S&T establishment without appropriate background or experience.

The Russian government has recognized these weaknesses and has developed a number of targets, plans, timelines, and goals to address them, including the passage of targeted measures and laws. Whether these actions will be effective and whether Russia has the management expertise and long-term stamina to execute them are discussed further below. Because of the nature of Russia's S&T weakness, any of the traditional indicators, such as public/private share and absolute level of S&T funding, patent activity, and venture capital investment, might provide useful insights into Russia's progression. Among them this committee rated the share of private, nongovernmental S&T funding the highest. Other high-priority indicators include the level of foreign S&T investment, the education and age of S&T personnel, and the export of high-technology products, which are discussed in more detail below. Indicators of average and below average priority include quality of scientific research institutions and numbers of scientific papers.

Share of Nongovernmental Funding

One of the main challenges facing Russia is its notorious weakness in translating fundamental research into industrial technologies. The share of government S&T funding should provide a meaningful measure of whether Russia is indeed making progress toward more entrepreneurship and private participation in S&T. In 2009 the share of government S&T in Russia was 72.9 percent, compared to 11.1 percent in the United States (Zashev, 2010). As long as the government share remains high, the approach to technology development remains top-down, and commercial and private entities remain marginally involved, it is unlikely that Russia will make real progress in overcoming its current weaknesses, especially its poor conversion rate of basic research into commercially or militarily viable technologies.

Level of Foreign S&T Investments

The level of foreign investments from multinational high-technology companies (e.g., Cisco or Intel) might be another very important gauge of Russia's progress in S&T, because it reflects not only Russia's international S&T competitiveness but also its general economic conditions and prospects. Multinational corporations will vigilantly monitor the Russian economy and innovation environment and will carefully weigh their options in Russia against those in other countries. Cisco recently established a venture fund in Russia, and even though its investment is relatively small ($60 million), it provides an example of foreign investment opportunities (Cisco, 2008). Naturally, Russia's economic health will determine whether it will be able to fund its ambitious transformation plans. If Russia continues to attract foreign S&T investments, then it is inevitable that pockets of functional S&T centers will be created, which will catalyze reform of the Russian S&T system. In addition, these investments (as in the case of Intel; see above) will usher in managerial skills and modern corporate practices, which Russia is lacking. Finally, foreign investments create partnerships and linkages to domestic companies and help to intensify competition, which could further accelerate Russia's progress. When monitoring the level of these investments, it is important to consider whether the foreign investors promote the development of innovative technologies in Russia or prefer other centers for R&D.

S&T Personnel

Other insightful indicators of S&T potential in Russia are the number, age, and level of education of its S&T personnel. Such metrics capture the extent to which Russia has been able to maintain and attract S&T talent through successful immigration policies and by providing desirable conditions for living and working. If the Russian brain drain continues and the overall Russian population continues to decrease or even remain static, there will not be personnel to staff the S&T institutions. It is also important that young scientists receive international exposure, either by attending foreign universities (and then returning) or by increasing the presence of foreign students and faculty in Russian universities. Without new ideas and greater involvement in the international S&T establishment, it seems unlikely that the Russian transformation effort will be successful.

Export of High-Technology Products

In the self-proclaimed target areas of medical, pharmaceutical, and information technologies, the international impact of Russian products is almost nonexistent. For example, Swiss exports of high-technology goods are worth several times more than Russian exports (Graham, 2010). The monitoring of such high-technology exports indicates the maturity and competitiveness of their technology and is not colored by the subsidies of state-funded programs to buy domestic goods.

FINDINGS AND RECOMMENDATIONS

It is expected that Russia will not succeed in developing a high-technology base to modernize the country and diversify its economy. This failure will create additional stress on the country and will foster Russia's increasing dependence on supplying and controlling energy technologies (e.g., nuclear power generation, pipelines, and raw materials), which will have implications for U.S. national security. It can be expected that, as one of the world's largest energy suppliers, Russia will fully leverage these technologies to advance its interests. More obviously, Russia's continued activities in space and nuclear technologies have implications for U.S. national security, in particular as Russia seeks to commercialize these technologies for sale to countries that are hostile to the United States.

Finding 7-1. Russia has a top-down approach to S&T innovation, which benefits a few areas that require large centralized investments and in which Russia has been historically strong, such as extractive industries, space, and nuclear systems. However the top-down approach to S&T innovation is self-defeating with respect to achieving goals in high-technology areas, which require a high degree of entrepreneurial innovation.

Finding 7-2. Due to its overreliance on a top-down approach, Russia is unlikely to be successful in modernizing the country and in diversifying its economy. Without globally competitive, high-technology products to sell, Russia is expected to be even more dependent on its role as one of the world's largest energy suppliers and providers of raw materials, and it will attempt to increase its control in this sector. Russia will potentially also exploit its nuclear and space capabilities to achieve its global political goals.

Recommendation 7-1. Russia's failure to achieve its modernization goals is not in the best strategic interest of the United States. It is recommended that the United States assist Russia in becoming a partner in the international S&T community by strengthening and increasing the number of long-term exchange programs and targeted international meetings, and increasing funding for joint research. In particular, those programs that provide exposure to the culture of U.S. universities, which have strong relationships with industry, would be advantageous.

Recommendation 7-2. The United States should develop an S&T strategy that moves toward energy independence, because Russia has a goal to become an energy superpower and has the potential to exploit this position to further its geopolitical ambitions.

CONCLUSION

Need for Transformation

Russia clearly has potential to become a world-class leader in S&T. However, as elucidated in this chapter, Russia must undergo major reforms to transform its S&T environment and fully leverage its potential. Some of these reforms extend beyond appropriating sufficient funding and establishing new policies or the usual governmental initiatives to transforming the economic sector on a major scale.

The Russian government recognizes these problems. In response it has developed detailed plans with clearly defined goals for the short, medium, and long term. However, there are several reasons to be skeptical of Russia's plan (Zashev, 2010). First, the proposed level of funding does not seem to be adequate. Budget shortfalls forced the Russian government to cut R&D expenditures for its short-term programs by up to 30 percent of the initially planned allocations. The current global financial crisis and decreasing demand for Russian natural commodities will intensify budget constraints.

Second and more important, Russia's S&T strategy is inconsistent and somewhat naive. Although the effectiveness of a top-down S&T approach can be debated, it is clear that the overwhelming dominance of the Russian government will not help the country achieve some of its main goals, namely increasing private participation and improving technology transfer from basic science to marketable products. For example, Russia's S&T plans and ambitions are constantly undermined by the tendency of the government to support large (i.e., government-controlled) companies and initiatives and the assumption that its top-level commissions and political managers have the expertise to select the correct "winners" in which to invest. Additionally, it is in engineering and manufacturing that Russia is most behind, and until it develops advanced manufacturing capabilities or at least determines a way to access them through international cooperation, Russia will not have significant impact in global markets. An approach that shields domestic companies from international competition will in the long run prevent industry from developing viable technologies.

Lack of Qualified Leadership

The nanotechnology initiative in Russia, which is the most important high-technology initiative, or at least thought to be so by the top political leaders, suffers as a result of leadership that lacks significant high-technology experience. Previous privatization schemes have placed the Russian economy in the hands of oligarchies with little experience. The list of projects that are being undertaken in the nanoscience endeavor does not indicate that Russian leaders understand what is involved in commercializing nanoscience advances; their approach neither improves the competitive environment nor encourages entrepreneurship. Those who are best able to recommend which technologies to pursue are not making the decisions. With the current political philosophy, it appears to be improbable that a more bottom-up S&T system with strong entrepreneurial elements can be created any time soon.

Rejection of International Partnerships

In strong contrast to the other BRIC countries, Russia maintains a hostile attitude toward foreign collaboration, which clearly is counterproductive to Russia's S&T goals. Although globalization of high-technology manufacturing and design has occurred in the other BRIC countries, certainly in Japan and Singapore, Russia is currently not engaged with the international community in any significant way. As the rest of the advanced industrialized world progresses (particularly in the areas of biotechnology and semiconductor development), Russia is falling further behind. The initiatives that Russia has chosen to close this gap will most likely have no positive impact on this situation. In fact, some of Russia's stated targets indicate that leaders do not understand the present state of the art. For example, one target for 2015 is to produce integrated circuit transistors of a size that was in volume production in the United States in 2009.

It is expected that Russia will be more successful in certain areas than others. The higher probability areas include nuclear power, space, and rocket systems, as well as energy distribution technologies involving the construction and exploitation of pipelines. These are all areas in which Russia is already quite strong. In fact these cases may be successful because a dominant governmental involvement with a central planning approach is advantageous and quite typical in other countries. However, Russia's goals in the areas of nanotechnology, life sciences, and information technology systems are certainly less likely to be accomplished. Experiences in other countries worldwide have shown that these high technologies require the intense participation of private enterprise.

In summary, even if Russia is able to meet the funding targets to support its current ambitious plans, it is improbable that Russia will succeed in developing a high-technology base to modernize the country and diversify its economy. This failure will create additional stress on the country and will foster Russia's increasing dependence on supplying and controlling energy technologies (e.g., nuclear power generation, pipelines, and raw materials), which will have implications for U.S. national security. It can be expected that, as one of the world's largest energy suppliers, Russia will fully leverage these technologies to advance its interests. Undoubtedly, this will have implications for the United States as the world's energy resources will be possibly controlled by Moscow. In order to monitor Russia's progress in S&T beyond the short term, there should be careful monitoring of the amount of nongovernmental funding, level of foreign investments, the education and age profiles of the Russian S&T personnel, and the entry of Russian products into international markets.

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8

Singapore

Singapore's strong leadership and top-down decision-making culture adapts as necessary to achieve national goals for science and technology (S&T) policy, planning, and execution. Singapore is expected to continue to achieve its S&T goals going forward. Singapore lacks natural resources and therefore relies on the highest-quality education, trade, and targeted innovation for security and prosperity. The stable government and absence of corruption attract foreign investment and workers. It aggressively recruits top international talent to leadership positions, builds universities and laboratories, and attracts multinational companies into its knowledge hub. Traditionally risk averse and product oriented, Singapore develops novel technologies to sell globally. It commercializes developments from small- to medium-sized businesses, using private and government incentives. Its efforts toward development of dual-use technologies target water purification, biotechnology, and renewable energy. Singapore is vulnerable to unfavorable swings in the global economy, and its internal capacity to handle internationalization, increasing individual independence, a culturally diverse international workforce, and a possible intrusion of terrorism could challenge the realization of national S&T objectives.

INTRODUCTION

It is very instructive that government officials in Singapore often refer to Singapore as "a little red dot," which is how it appears on any large-scale map. With neighbors who have been less than friendly at times, the country focuses on being as economically and militarily strong as possible and on forging cooperative links with other countries in Asia and in the West. Singapore has no natural resources other than its people. A multiracial country, it places a high premium on developing all of its citizens through education and rewards for merit. Since its independence from Malaysia in 1965, Singapore's leaders have focused on attracting both industry and educated people to the island.

During the 1960s, Singapore established itself as a center for low-cost manufacturing as a strategy for strengthening its economy. As this strategy became less viable because of rising living standards and competition from other Asian countries, Singapore shifted its major focus to trade. Singapore leveraged its strategic location in the Malacca straits to become the second-largest shipping center in the world. The nation's strong maritime focus is reflected in its naval strategy.

In order to further national development, political and military leadership has emphasized higher education and the development of an economic strategy that leverages national strengths to fill a global niche. Singapore's strong central leadership has proven to be effective, flexible, and insightful. Leaders are traditionally sent to the best educational institutions in the world to earn advanced degrees and to bring back knowledge to Singapore. As a disincentive for corruption, leaders are paid well and assessed strong penalties if found to be involved in corruption.

Singapore's forward-looking government periodically assesses what areas should be the next to develop, and then attempts to address them. As a small country with a high level of governmental control, Singapore can successfully execute changes in its strategic direction. It is noteworthy that the government seeks international advice in the process of developing both strategy and tactics for economic development and corresponding S&T support.

NET ASSESSMENT OF S&T INVESTMENT STRATEGY

In 2006, Singapore's Ministry of Trade and Industry published an S&T strategy document that summarizes the nation's broad plan for S&T advancement:

> Singapore's economic strategies must keep up with the changing global economic landscape. Singapore must continue its process of upgrading and renewal to ensure that it remains competitive in a global knowledge economy. It needs to develop its innovation capacity as a new, sustainable source of competitive advantage.
>
> Given its strengths in science and mathematics, Singapore is naturally positioned to excel in S&T. To succeed, talent will be key. Singapore must become a global talent hub, attracting talent here by providing a vibrant environment and an open society that offer opportunities for communities of creative and talented people. (MTI, 2006)

Specifically, the areas that appear to be targeted for S&T support and technology transfer for economic development in the near future include water resources, control of infectious diseases, interactive and digital media, and biological engineering and science. Singapore has also declared that it aspires to be the education center of Asia, both to attract outstanding people who will stay in the country and also to bring income into the country. It has announced plans to open an elite university, which will have a much larger percentage of foreign students than the premier National University of Singapore. The new university will be focused around design for both engineering and architecture. Singapore has formed partnerships with universities from around the world to attract world-class academic scientists and engineers to work in its universities and research institutes.

In terms of military investment strategy, Singapore is dedicated to having a fifth-generation, highly networked force that is the best in the region. It aims to make it very costly for any country to attack it. Given how dependent Singapore is on the flow of goods via the maritime sea lanes, the country has invested in control of the sea lanes for some distance into the Straits of Singapore. All male residents of Singapore are required to serve in the military and then in the reserves.

The government of Singapore develops plans for S&T in five-year cycles, and the current plan (2006-2010) is nearing its conclusion. In comparison with its predecessor plan, the current plan almost tripled research and development (R&D) funding, raising it to S$13.9 billion (approximately U.S.$9.8 billion). At the onset of this plan, a high-level Research Innovation and Enterprise Council (RIEC), chaired by the prime minister, was formed to oversee national R&D policy. The RIEC has a three-part mission (Yeoh, 2010):

- Catalyze new industries through strategic research programs
- Expand research capacity to create new knowledge
- Nurture innovation and entrepreneurship to exploit new knowledge

These goals are consistent with the point of view that innovation is crucial to Singapore's ability to stay ahead of the lower-cost competition.

Singapore has established an impressive set of international panels for deciding on what research to fund. These panels have the attention of the government at the highest levels and ensure that the work is well supported and that the choices meet international standards. Indeed Singapore has embraced international input into its S&T development at all levels, and human capital has possibly made a greater impact than the financial support from global corporations. For example, in 2006 foreigners formed 30.9 percent of the total employment pool. Well-known scientists and engineers have been recruited to the research institutes, including Charles Zukoski, who chairs the Science and Engineering Research Council (SERC),[1] Edison Liu, the executive director of Singapore's Genome Institute,[2] and Kerry Sieh, the director of Singapore's Earth Observatory.[3] Singapore currently is a world leader in per capita metrics of innovation, including U.S. patents.

More impressive is the concerted federal approach to transitioning the results of R&D to the private sector. The government shifted its focus from cost-effectiveness and efficiency toward knowledge as the driver (Vedem et al., 2009). Although the Singapore Economic Development Board executes strategies to make Singapore a global hub for business investment and talent, the Standards, Productivity, and Innovation Board (SPRING) supports the development of small- to medium-sized enterprises with funding to execute intellectual property (IP) strategy, hire external experts, and contract R&D from the research institutes. Grants of up to $10 million are among the support vehicles available for companies to commercialize Singapore-based technology. The 14 research institutes are increasingly tasked with developing a pipeline of research talent to meet industry needs; for example, education products have been produced for school children, and for undergraduate, master's, and nascent doctoral-level programs—including a joint engineering and business doctorate (Vedem et al., 2009).

Many of these new initiatives are bearing fruit. Venture capital firms are working closely with the research institutes and technology incubators to develop spin-off companies. As of 2008, 72 percent of R&D funding was supplied by the private sector (Yeoh, 2010). As an example of knowledge-based economic growth, the number of nanotechnology-related companies has grown from 10 in 2004 to 58 in 2009 (Vedem et al., 2009). Other successful spin-off companies are developing medical devices, organic photonics, high-efficiency solar cells, water purification and waste treatment systems, and ultra-low power electronics. Many of these products are directly applicable to defense and homeland security systems. The close personal relationships among government leaders and between civilian and military leaders in Singapore facilitate the transfer of R&D products for military as well as civilian applications.

S&T INVESTMENTS OF INTEREST

Singapore has a well-defined vision for national security, based on establishing itself as a valuable partner in the information age and on making an attack on its territory prohibitively expensive for potential enemies. In order to realize these goals, Singapore has planned an S&T strategy around its unique national needs and its drive to create a highly educated and technologically developed society. The degree to which Singapore solicits international advice for planning and carrying out national initiatives is exemplary, and works very well in its highly centralized, stable, supportive federal system.

Singapore has identified a number of driving forces for R&D on the global stage. These are aging, renewable energy, climate change and sustainability, urbanization, infectious diseases, food security, and water supplies. In particular, the country wants to become a major economic powerhouse by finding innovative solutions to its identified challenges and selling the knowledge it has developed.

For example, Singapore is conducting considerable research on how to develop and process its water supply. As access to water becomes more important in countries like India and China, Singapore intends to sell its knowledge to cities in these areas. This is often referenced in Singapore as the "Singapore water story."

Another area of focus is infectious diseases, and more generally biotechnology. Singapore has invested heavily in the development of basic understanding of biotechnology as well as the technology to detect and control the spread of infection. This type of knowledge enables it to respond quickly to emerging threats, as it did for the SARS epidemic, and provides technology for export to address global health problems.

In light of the continuing issues surrounding climate change in the world, Singapore is looking both at compact energy sources, especially renewable ones, and at geo-engineering. The need for compact energy sources is driven by the fact that Singapore is a small country. Given the lack of countries in the world that agree on climate

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[1]For more information, see http://www.a-star.edu.sg/AboutASTAR/CorporateProfile/ASTARBoard/ProfessorCharlesZukoski/tabid/905/Default.aspx. Last accessed May 27, 2010.

[2]For more information, see http://www.gis.a-star.edu.sg/internet/site/investigators.php?f=cv&user_id=14. Last accessed May 27, 2010.

[3]For more information, see http://www.earthobservatory.sg/index.php?option=com_eos_people&view=people&layout=details&task=details&filtertype=MANAGEMENT_TEAM&Itemid=4&id=9. Last accessed May 27, 2010.

mitigation techniques, the development of geo-engineering technology will position Singapore well to be able to sell this type of technology.

Another high-impact technology focus is development of digital media and content. The already substantial investment in digital gaming will be parlayed into industrial domination of the expanding education and training market in Asia. The investment in new virtual reality environments will allow for substantially enhanced training in defense-related areas. This is important for a small country like Singapore, where land area is at a premium.

The areas that have been targeted for military development are the following: networked command and control, unmanned aerial vehicles (UAVs), and system architecting. Singapore has developed system architecture to a world-class level. One example is the use of congestion control, a system where drivers purchase access to busy roads during peak times, for traffic management. Singapore led major world cities in implementing this economically driven means of controlling traffic (Gopinath Menon, 2002). Singapore's work on water supply control is also among the best in the world. All sewers in Singapore are connected to its wastewater reclamation system, which produces ultrapure water that can be used for a variety of industrial manufacturing applications in addition to standard domestic use (Tortajada, 2006). In the area of UAVs, Singapore lags behind both the United States and Israel, whose programs are driven by current security needs. Nevertheless, the combination of expertise in UAVs, systems architecting, and simulation software could lead to unique products of great military value.

PROJECTED ADVANCES IN S&T PROFICIENCY

Singapore has done very well in realizing its five-year goals, and—given the stability of its administration—there is no reason to doubt that it will continue to do so. Decisionmakers have focused on S&T that will make a difference both nationally and internationally and have built incentives for companies to commercialize the S&T, so that S&T products will support economic development and create new markets for Singaporean products. The threats to realizing the goals of the five-year plans are international in origin: for example, the current global recession may temporarily reduce R&D investment by global corporations that Singapore had projected to increase as a percentage of gross expenditure on research and development.

Singapore is likely to achieve its stated S&T aspirations. United, effective leadership and continued global and national commercial investment support the realistic national goals set forth in the five-year plans. In the longer term, Singaporean leadership has demonstrated the willingness to make major changes in the national goals in order to change the culture and lifestyle of its citizens: for example, from agrarian to low-cost manufacturing, to a focus on maritime trade and electronics, high-tech materials, education, healthcare, and clean technology. Part of the success is breaking down long-term goals into aggressive but realistic five-year chunks.

NATION-SPECIFIC INDICATORS OF S&T ADVANCEMENT

As with all of the countries studied in this report, a diverse set of indicators are needed to form a complete picture of Singapore's S&T environment. Because the nation's strategy for continued growth depends on attracting international talent and funding, the quantity and focus of foreign investment is an important indicator of success. In addition, indicators related to improvements in higher education (e.g., number of foreign students, faculty members, interdisciplinary degrees, Ph.D.s per year, and international collaborations) will measure Singapore's ability to achieve its goals for producing talent. Corporate and government expenditures on R&D, formation of new companies and products from university and industry collaboration, and enactment of laws promoting entrepreneurship can also be monitored to assess the growth of the national S&T environment.

Although the numbers of papers, patents, and citations attributed to Singapore can be useful metrics of R&D productivity, they can be misleading because of the level of international collaboration and corporate activity in this small country. The numbers of papers or patents that can be attributed to discovery or innovation by Singaporean establishments may be hard to determine. Also, indicators expressed on a per capita basis may imply higher impact than is realistic. Singapore has a lot of intellectual endeavor and has formed an excellent environment for innovation, but the country's size renders the total effort relatively small compared to that of much larger countries.

Singapore has taken advantage of its small size and highly centralized government to begin ambitious initiatives and instigate changes rapidly. With the fifth-highest per capita GDP in the world (2007 purchasing power parity was $50,936,059), Singapore rates very highly in terms of the many indicators relevant to S&T support and innovation (IMF, 2008). These metrics include education, international recruitment of Ph.D. scientists and engineers, GERD, and innovation. The political focus on S&T as a means to advance the standard of living and to achieve military security guides the selection of key areas in S&T and drives social evolution that supports a well-educated consumer base, global outreach, and strategic alliances.

Education in Singapore is highly centralized and highly valued. Over the past decade, state initiatives have established standards for education at the pre-college level that require proficiency in English, inclusion of the religious schools, and centralized training for teachers and school principals. Singapore has expanded its university system and established relationships with international universities such as Massachusetts Institute of Technology, University of Washington, Southampton University in Britain, ETH in Switzerland, and the Technion in Israel. A total of 97,000 students from 120 countries went to Singapore to study in 2008, a 50 percent increase from 2003. Foreign students are mainly from China, India, Indonesia, Malaysia, Myanmar, South Korea, and Vietnam (Yeo, 2009). About 200 students receive the generous Agency for Science, Technology and Research (A*STAR) fellowships to cover both undergraduate and graduate education, with a six-year commitment to work in Singapore thereafter. Another example of Singapore's recruitment efforts can be found in the National Research Foundation Research Fellowship Scheme,[4] a program that offers postdoctoral students generous funding for "projects that exhibit high likelihood of a research breakthrough."

The Defense S&T Agency (DTSA), established in 2000 to support the Singapore Armed Forces, also invests in the education of Singaporeans through the DTSA College, with a focus on systems engineering and business skills. DTSA sends promising members to overseas universities on postgraduate scholarships in defense science and engineering, information technology (IT) and communications engineering, and building and infrastructure. The people who receive these fellowships must return to Singapore to use their skills in support of the country. DTSA has a relationship with the U.S. Naval Postgraduate School and offers a joint degree.

Recruitment of international scientists and engineers has been initiated at an impressive level (Arnaud, 2006). Unique facilities at Biopolis and Fusionopolis, coupled with an extended funding commitment that liberates top R&D talent from the obligations of proposal preparation, have attracted world-renowned talent. Singapore is actively leveraging this activity to educate local students and R&D staff, to create spin-off technologies in local incubators, and to increase its international IP position. From 2001 to 2005, Singapore's international ranking in IP rights improved from 17th to 4th in the number of patents in force per 100,000 inhabitants (IMD, 2005). Although a significant number of those patents may be held by multinational companies, the know-how can be transferred to local companies, and a strong IP regime supports the promotion of Singapore as an R&D center.

Singapore is increasing its commitment to transferring the technology developed in the R&D establishments to industry, although the culture in general remains risk-averse and public policies toward entrepreneurship can be conflicting (Carney and Zheng, 2009). Despite the impact of investment by multinational corporations in Singapore, 42 percent of the GDP, 23 percent of manufacturing exports, and 62 percent of employment are generated by small- to medium-sized enterprises (MTI, 2006). The culture of collectivism in Singapore leads to expectations that superiors will provide the initiatives for growth and improvements; this expectation may slow the integration of S&T results into manufacturing (Zhou et al., 2009). The Growing Enterprises with Technology Upgrade (GET-UP) program has been started to aid small- to medium-sized enterprises with technical assistance and manpower support, financial assistance, and overseas marketing.

FINDINGS AND RECOMMENDATIONS

Singapore is a highly centralized, stable, agile country that has become a regional hub for education and innovation. Its policies promote integration of multinational high-tech endeavors to address national problems for continued economic development. It relies on foreign investment, but it has created a legal system and qual-

[4]For more information, see http://www.nrf.gov.sg/nrf/otherProgrammes.aspx?id=142.

ity of life that attract foreign experts and funding. The United States has strong ties with Singapore in defense, education, and research, but Singapore has also developed alliances and cooperative agreements in these areas with most of its Asian neighbors and many European partners. Singapore faces future challenges to balancing its current, tightly controlled culture with the influx of foreigners, new ideas, more highly educated citizenry, and potential for terrorist attack.

Singapore is taking full advantage of its highly centralized government to push advanced innovation-based development as a means to improve the standard of living of its citizens and to ensure military and economic security. Government strategies for advancing education and encouraging foreign investment have resulted in (1) importation of international scientists and engineers capable of cutting-edge discovery, (2) creation of an innovation ecosystem in which Singaporeans are learning the tools required to commercialize scientific breakthroughs, (3) slow change from a risk-averse culture toward one that encourages small- to medium-sized enterprises, and (4) a stable, well-educated community for continued attraction of global business investment.

The specific tactics outlined in each of the past three five-year plans have been efficiently executed, with Singapore achieving world leadership in water technology, data storage, and systems architecting. Small- to medium-sized enterprises are a major economic force and are increasingly utilizing technology produced by the S&T community. The S&T infrastructure is exceptional and should support increasing levels of technology transfer and production of high-technology products. The S&T infrastructure and the creation of laws and culture friendly to global business assure that the innovation ecosystem will remain strong in Singapore. Native Singaporeans are already learning not only how to do S&T, but also how to take financial risks and to innovate and leverage S&T for commercialization. Eventually they will lead global corporations.

The current R&D plan establishes the goal of increasing the GERD to 3 percent of GDP by 2010, an objective that will likely be achieved. The target for 2015 is for the GERD to reach 3.5 percent, primarily by increasing the private-sector share (MTI, 2006; Yeoh, 2010). Singapore has incentives in place to attract multinational R&D and high-tech manufacturing, but the state of the global economy must change before a further influx can be encouraged. Singapore will continue to offer political stability, lack of corruption, an English-speaking population (with Mandarin second), 10-year tax holidays, and training subsidies for new employees. Land will remain expensive and labor costs high. The lack of corruption combined with relatively high salaries makes Singapore a particularly attractive place to undertake research.

From a political standpoint, Singapore is best served by maintaining peace with all its neighbors. Its ties to both the United States and China must remain strong. The interaction with the United States is through military as well as economic and educational exchanges. Although the export of U.S. military technology overseas is always a concern, the advantages of strong linkages with Singapore and the potential for two-way exchange of defense-related technology should be appreciated.

Finding 8-1. Singapore is currently importing discovery capability, fostering innovation successfully, and developing international markets for its S&T products (including education). Although the innovation ecosystem includes national IP protection and fosters development of products from S&T endeavors, it is also a center for global information exchange. Singapore is also specifically a leader in solving problems unique to maritime trade and urban environments, and these solutions will become increasingly useful in China, the United States, and other countries.

Recommendation 8-1. The United States should be very involved in the S&T initiatives in Singapore in order to ensure two-way information exchange and to maintain critical military and economic alliances.

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9

Military and Economic Implications of Science and Technology Developments

INTRODUCTION

This chapter analyzes the science and technology (S&T) strategies of Japan, Brazil, India, China, and Singapore (JBRICS) to assess their potential impact on each country's mid- to long-term economic competitiveness and military capability. Each country's assessment depends on its (1) S&T planning for national security, (2) likely S&T progress over the next 3-5 years and 10 years and beyond, (3) most likely time required to achieve its goals, (4) priorities for S&T research with high potential impact on economic competitiveness and military capability, and (5) country-specific indicators of progress toward national goals.

All six countries, reflecting the powerful macroeconomic pressures of globalization and the attraction of the U.S. national innovation system, grasp the importance of S&T investments to bolster economic competitiveness—which is viewed by all of them as a national security issue—and to increase military capabilities. Together, these six countries represent a cross-section of a world where countries increasingly view technology development as a high priority and where technical know-how flows freely across borders.

Among the JBRICS countries, S&T investment programs target a range of high-impact technologies including information technology (IT) and telecommunications (from microchips to supercomputers), nuclear energy, alternative energy, water purification, ocean exploration, space, biotechnology, agricultural science, and green technologies. Yet the countries are markedly different in their approaches to S&T investment, taking their own distinct paths toward development of a national innovation system—the network of institutions, public and private, that foster the development and diffusion of new technologies. This variable picture is representative of today's global S&T environment, which is likely to remain unchanged for the foreseeable future.

GRASPING THE TASK

This chapter draws on the insights of the full study to analyze the relationship between each country's S&T strategy and its military capability. The committee could estimate the likelihood of the countries achieving their 3- to 5-year national goals but had little confidence in its ability to forecast their successes beyond 10 years, because this requires consideration not only of internal resource-driven factors but also of geopolitical factors involving countries not studied in this report.

China and Singapore, appearing at opposite ends of the gross domestic product (GDP), population, and national-resource scales, quickly emerge as the countries for which S&T investments are most closely aligned with economic growth and military modernization. They are the most effective at managing the dynamic tension between their strong top-down investment strategy and their still-developing bottom-up S&T innovation environments. Their autocratic political systems demonstrate the overriding importance of leadership in developing a sustainable commitment to innovation. Among the six countries, only China and Singapore will essentially meet their five-year goals.

Brazil, Japan, and Russia will be slower to achieve both their economic-growth targets and their innovation goals for a variety of country-specific reasons. These include ineffective governance, misaligned economic and security priorities, infrastructure deficits, weak government-to-industry links, educational shortcomings, natural-resource scarcities, and political and cultural resistance to needed reforms. India must overcome substantial financial shortcomings to meet its three- to five-year investment goals for education and research, which seems unlikely to happen. However, its 10th Five-Year Plan that culminated in 2007 was considered a success, so significant achievements are expected.

For the next decade, the United States will remain the global leader for government investment in S&T and for cultivation of a powerful, national innovation environment. However, the dominance of the United States in S&T will likely decline as rates of S&T investment rise in China and other countries. There is considerable concern, for example, about the future of the science, technology, engineering, and mathematics (STEM) workforce in the United States. A 2006 survey of member states in the Organisation for Economic Co-operation and Development (OECD) found that 15-year-olds in the United States performed “significantly below” the OECD average in both science and math, ranking 18th and 24th in each, respectively (OECD, 2007). Moreover, there has been serious slippage by the United States in some competitive categories—including the quality of elementary and secondary education, the provision of academic and societal incentives to study science, and a post-9/11 decline in attracting foreign S&T talent (NAS, NAE, IOM, 2007). Such deterioration might represent a distant concern for a country with such a commanding lead in innovation, but the concern is actually more urgent in the context of today’s rapid advancement of emerging and disruptive technologies.

This six-country survey points out growing security concerns that arise from the dynamic, increasingly globally dispersed nature of R&D itself. This unprecedented phenomenon increases the opportunities for technological surprises as many countries, working alone or in concert, can discover, uncover, or create breakthroughs in high-impact technologies in areas such as microprocessing, genomic profiling, biomedical engineering, and drug therapy, or can develop disruptive technologies from new knowledge or from the innovative application of existing technologies.

In addition, multinational corporations with operations in multiple countries are often more powerful than governments in influencing market trends. The United States, which for most of the Cold War era aggressively protected its position as the global center of R&D, now confronts a serious international security challenge that will require increased attention to U.S. capabilities in strategic areas and greater collaboration globally.

The linkage between science and security must have a rigorous, interdisciplinary focus that integrates geopolitical and socio-cultural analyses of government capabilities, strategies, motivations, and intentions with emerging and globally dispersed disruptive technologies. It must be recognized that security-related forecasts are becoming more uncertain and that unexpected events are certain to occur with greater frequency than in the past.

The stakes are high. The United States today is threatened by technological surprises more than it has been at any time in its history. Research and analysis can help tie the uncertainty to geopolitical changes, global financial upheavals, and the S&T revolution—assuming we have the necessary tools to detect and monitor these trends. But the United States cannot eliminate uncertainty or even reduce it to Cold War levels. The recently published *Quadrennial Defense Review* (QDR) summarizes the impact of this reality on the Department of Defense’s (DoD’s) S&T program (DoD, 2010):

> As global research and development (R&D) investment increases, it is proving increasingly difficult for the United States to maintain a competitive advantage across the entire spectrum of defense technologies . . . the DoD S&T program is struggling to keep pace with the expanding challenges of the evolving security environment and the increasing speed and cost of global technology development.

CURRENT CONTEXT

Today's world of politics, economics, and science is dramatically different from the world of 25 years ago when the United States was the global economic power and the center of worldwide R&D. The geopolitical revolution that swept away the Soviet Union and the Warsaw Pact at the end of the 20th century has led to the emergence of a multi-polar world in which China, India, and Brazil are able to assert themselves effectively and Russia is adjusting to a significantly reduced role on the world stage. Globalization has led nations, multinational corporations, nongovernmental organizations, and individuals—scientists prominently among them—to exploit international networks for unprecedented levels of collaboration for noble purposes.

Globalization has also provided to state and non-state actors increased access to exploitable information, technical know-how, international finance, and potentially catastrophic destructive capabilities. Multinational corporations, for their part, now operate with a "quasi sovereignty" beyond the reach of many host governments, which enables them to exploit their superior access to global information flows and to the best technical and professional expertise. This changing geopolitical landscape with its discernable shift of power and influence from West to East has clearly energized and emboldened the six governments in this review. They see opportunity in this multi-polar world, especially when they perceive themselves to be one of those poles (NIC, 2008; DoD, 2010).

Globalization, arguably the defining phenomenon of our time, has accelerated this geopolitical transformation. The unprecedented IT-driven, real-time flow of information, finance, people, goods, services, and cultural perspectives across borders has promoted global integration. It also has contributed immeasurably to the rapid economic growth of China, Singapore, India, and Brazil, and it has presented only partially realized growth opportunities for Japan and Russia. The National Intelligence Council (NIC) has produced four global trends studies over the past decade, the last three of which point to the growing role of China, India, and Brazil in a world in which the United States will wield dominant but diminishing power (NIC, 1997, 2000, 2004). The most recent NIC estimates can be found in *Global Trends 2025: A Transformed World* (NIC, 2008). Significantly, the recently published QDR concurs with the NIC assessment of economic and geopolitical trends, including with regard to the diminished role of the United States in a multi-polar world (DoD, 2010).

Globalization also has accelerated the trend that scientific investigation and R&D are less in the domain of a few major developed countries and more in the domain of multiple countries and global networks. This results in increased challenges for the United States. It is more difficult not only to monitor fast-track, emerging technologies but also to stay ahead of globally dispersed breakthroughs in disruptive technologies. These are often low-visibility, high-impact breakthroughs and can occur in a variety of fields, including information technology (IT), genetics, materials technologies, neuroscience, agricultural science, or robotics. One frequently cited example of a disruptive technology is the improvised explosive device (IED), which repurposes existing technologies to create improved, disruptive capabilities in warfare (NRC, 2010).

The National Research Council (NRC) report *Persistent Forecasting of Disruptive Technologies* states:

> A scientific breakthrough can lead to not just a single disruption but to a series of them. The discovery of the electron in 1879 led to new technologies that were progressively more disruptive and caused long-lasting changes in the availability of products and services: transistors . . . , integrated circuits, and microprocessors . . . are the direct result of scientific and technical breakthroughs. Other advances are the result of an innovative application of existing technologies to new markets and problem sets: for example, Internet social networking Web sites (e.g. Facebook, MySpace, and LinkedIn), improvised explosive devices (IEDs), and portable digital music players such as the iPod . . . Some new technologies will cause shifts that change the world; others will remain laboratory curiosities that are never seen outside basic research centers. Still others will be something in between. (NRC, 2010, p. 11)

Globalization exposes the vulnerability of countries and peoples within countries that are less able to compete globally. This adds to the uncertainty in predicting national outcomes and global trends in a new world characterized by chronic financial volatility and widening income gaps between developed and underdeveloped economies. South Asian scholar Amit Pandya describes current economic trends in stark terms in his article, "The Shape of Change: Nature, Economics, Politics, and Ideology":

> The dominant picture is of two-tiered societies, divided between the few who through ownership of capital assets or through education, are able to aspire to global standards of living, and the vast numbers mired in underdevelopment. This is seen most sharply in India, owing to the rapid rise of its internationally competitive economic sectors and its multinational corporations. . . . (Pandya, 2008, p. 276)

Leading economic analysts worldwide, both in the government and the private sector, did not foresee either the 1997-1998 global financial crisis that originated in Thailand or the 2007-2008 global meltdown that began in the United States.[1]

The Expanding Global Threat Assessment

For the second half of the 20th century, the United States defined global security largely in terms of the single strategic threat from the Soviet Union. Today, global threats are more complicated and more distributed, with growing numbers of real and potential adversaries with destructive capabilities. No longer do we and our allies enjoy the advantage of being in the S&T center of gravity, which is shifting eastward. Intelligence analysts now benefit from the Internet and from advanced technical collection systems that provide real-time data on unfolding crises. However, the difficulty of predicting the crises is more difficult—as is the ability to foresee scientific and technological breakthroughs.

National security analysis today is multidisciplinary in scope and international in perspective. Analysts assess wide-ranging sources of threats involving sociocultural, demographic, environmental, and health issues that in an earlier era received much less attention from the intelligence community. Regarding the environment, for example, the U.S. intelligence community deemed global warming to be a serious national security issue in the 2008 national intelligence estimate (NIE) and issued related conference reports on several countries including China, Russia, and India (Fingar, 2008; NIC, 2009a,b,c).[2]

Identifying Drivers

Global security today encompasses broad and diverse issues that "drive" leadership decision making on economic development, military modernization, and S&T investment. These policy-shaping issues have different country-specific significance and include, for example, human capital, education, health, age distribution, migration, competition for natural resources (e.g., food, water, energy), health and infectious diseases, migration, humanitarian crises, globalization, emerging and disruptive technologies, national and international governances, corruption, threat perceptions including views of the United States, the rule of law, and international competition in ocean exploration and space.

Focusing on these drivers helps to assess the relative capacities of the JBRICS countries to achieve their goals for S&T investment, economic growth, and military modernization. The same issues that drive policy serve as socio-economic-political and cultural indicators of progress. Brazil is both challenged and assisted by its young population, while Russia and Japan are weakened by aging societies. Japan and Russia have declining populations. In contrast to Japan, which resists immigration to its disadvantage, Singapore welcomes immigration to its economic advantage. China and India have chronic energy shortages, while Brazil is energy independent. China, India, and Brazil lack clean water resources. Russia's health care is deteriorating. Systematic corruption stymies economic growth in Russia and has negative impacts in China, India, and Brazil. India, Russia, and Japan have significant governance problems that impede growth of national S&T innovation environments. All of these socio-economic, political-cultural trends can be tracked over time and should be factored into S&T forecasts.

Some general security trends can be monitored using open sources. China's suspicion of the United States complicates the bilateral relationship between the two countries. Moscow's antagonism toward Washington adds to Russia's priority for security over economic development. India worries about competition from China, but it

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[1]The continuing challenge of anticipating global financial crises is analyzed in National Intelligence Council, *Global Trends 2015*, p. 38, and *Global Trends 2025*, pp. 10-12.

[2]The NIE and the conference reports can be found at http://www.dni,gov/nic/special_climate2030.html.

is the persistent hostility with Pakistan that diverts large amount of its resources—including R&D—to military programs. All the countries studied, however, share a common motivation to understand, monitor, and exploit fast-moving global technology trends and to engage international networks that can help to advance this goal.

There is no set of indicators that provide a reliable assessment of progress toward breakthroughs in high-impact technologies for any country. Tracking trends in the awarding of advanced scientific degrees, publications in scientific journals, or issuance of patents can be marginally useful in identifying issues for further research but can be quickly discounted because of quality-control and reliability problems. The goal in the open-source world is to target those publications, conferences, or networks where research has undergone a most rigorous peer review and is selected by top scientists for presentation and serious dialogue.

Flagging Uncertainty

Dealing with uncertainty and preparing for the unexpected are core national security missions, which have become more challenging to accomplish than ever before. We are confronted by the increasing globalization of R&D, the real-time diffusion of technical know-how through international networks, and the coalescence of advancing technologies. We also are faced with the inextricable linkages between dual-use capabilities and the motivations and intentions of national leadership, and between the increasing potential of path-breaking technologies, or disruptive technologies, and heightened military capabilities.

The continuing global S&T revolution has brought impressive economic prosperity and notable social progress to many countries in the world. However, it also has elevated the possibility of catastrophic damage from dual-use technologies. The potential impact, for good or bad, of rapidly advancing innovations in such diverse areas as IT, biological sciences, neuroscience, material sciences, nanotechnology, and robotics becomes even more gripping when they are viewed as an interconnected and fused whole. U.S. adversaries, big and small, are gaining increasingly easy access to a wide range of technologies that can be used to improve their military capabilities.[3]

Assessing Military Impact

Military modernization is a commanding priority in China, Russia, India, and Singapore, and less so in Brazil and Japan, but the resulting implications for U.S. national security vary widely. China credibly integrates its S&T-focused military modernization objectives into its broader, overriding goals for economic development. Singapore's S&T-supported military goals are consistent with transparent national plans that are aligned with U.S. national interests and are generally not a threat to those interests. Much the same can be said for Brazil. India's investment in security is disproportionate because of its concerns about China and, even more, because of its chronic, hostile relationship with neighboring Pakistan. Russia uses increased military strength to counter its declining economic, political, and diplomatic stature in the world, which is potentially more troubling.

In spite of this assessment, it is difficult to be definitive about the implications of each country's efforts at military modernization because of the globalization of R&D and the declining ability of the United States to control the export of its dual-use and military-sensitive technologies. Military R&D programs usually lack transparency in open-source research, including those in many democratic countries. In unstable regions, however, governments often put greater emphasis on protecting themselves against perceived security threats than on increasing economic opportunity.

For some countries in our study, history illustrates this point. Past military regimes in Brazil, according to the successor democratic governments there, secretly pursued a nuclear weapons capability into the mid 1980s as a hedge against Argentina's political dominance of South America[4] (Spector, 1988). Democratic India, motivated by its hostile relations with both Pakistan and China, twice surprised the United States with unannounced nuclear

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[3]For more information and a relevant global survey of S&T trends, see RAND Corporation, National Security Division, 2006, *The Global Technology Revolution 2020, Bio/Nano/Materials/Information Trends, Drivers, Barriers, and Social Implications,* Santa Monica, CA: RAND Corporation.

[4]For a brief history of Brazil's nuclear program, see Sharon Squassoni and David Hale, 2005 (October), Brazil's nuclear history, *Arms Control Today*, available at http://www.armscontrol.org/act/2005_10/Oct-Brazil-History.

tests in 1974 and 1998. Both China and Russia developed secret nuclear programs, and Moscow continued its vast biological weapons program long after it committed to dismantling it during the Nixon administration.[5]

These historic realities, which confirm the lack of transparency of research on military programs, have modern equivalents. The United States has limited information on the military R&D of both China and Russia, and it appears that both countries have developed considerable offensive cyber capabilities. At the lower end of the technical-capability spectrum, insurgent groups and international terrorists, working alone or in secret collaborations with nation states, have focused their attention on enhancing lateral technologies to challenge adversaries. For example, terrorists and insurgents in Iraq, aided by Iran, have used increasingly lethal improvised explosive devices (IEDs) over the past several years to inflict the majority of U.S. casualties (CRS, 2007). During the Arab-Israeli conflict in Lebanon in 2006, Hezbollah, assisted by Syria and Iran, used technically enhanced IEDs and missiles to hold off the Israeli military long enough to transform a military defeat into a political victory in the eyes of many observers (CRS, 2006).

Examples of military programs past and present demonstrate little correlation between the strength of a country's economy and its investment in technologies for military purposes. For most of its existence, the Soviet Union invested disproportionately in S&T for military purposes as its economy foundered. Russia continues to favor military options, such as space and rocket systems, over investments that would expand the Russian S&T capacity, promote economic growth, and improve the declining quality of life for the majority of Russians.

NET ASSESSMENT BY COUNTRY

A driver-based analysis is useful in assessing the strengths and weaknesses of countries' S&T programs, as well as in gauging their potential to meet their strategic objectives over the near-, mid-, and long terms. In a field with uneven and incomplete data, however, deeper insight can be gained by integrating the drivers into a net assessment for each country. Without this integrated approach, the analysis of sensitive issues such as dual-use technologies will struggle for relevance.

China

Distilling the findings in Chapter 4, China emerges as the greatest economic and military competitor of the United States. Its growth rate may slow, its regional social and economic disparities may increase, its corruption problems and environmental degradation may persist, its excessive control of information flows may impede growth, and its business policies may continue to be inefficient. Nonetheless, as the National Intelligence Council (NIC) concludes in *Global Trends 2025* (2008, p. vi):

> China is poised to have more impact on the world over the next 20 years than any other country. If current trends persist, by 2025 China will have the world's second largest economy and will be a leading military power.

China's focused, top-down S&T investment will be the principal driver of this impressive growth. Its S&T investment strategy is narrow but coherent, with strong but centralized support from a highly technical politburo led by engineers and adequate funding dedicated to explicit strategic goals. The government is incentivizing the study of science in an improving educational system, and it is encouraging controlled international partnerships and professional networks to foster domestic S&T development. It is also seeking to develop its bottom-up innovation environment of individuals and organizations. This remains an open issue, because it is not clear that the freedoms and independence required to do so will be allowed.

China's government apparently believes that high economic growth rates can be sustained while maintaining social stability across the vast country—an uncertain proposition. But there is little doubt that Chinese leaders view continued high economic growth as imperative to maintaining political and social stability. Consequently,

[5]For a historical perspective on the USSR's biological weapons program, including on its post-Nixon-era treaty violations, see Ken Alibek, 1998, Behind the mask: Biological warfare, *Perspective* IX(9, Sept.-Oct.), available at http://www.bu.edu/iscip/vol9/alibek.html. Dr. Alibek is the former first deputy chief of Preparat, the Soviet Union's biological weapons program, and *Perspectives* is a periodical of the Institute of the Study of Conflict, Ideology, and Policy (ISCIP).

it considers an external military confrontation to be a serious threat to and an unwanted distraction from that goal. The success of China's integrated economic, S&T, and military modernization plans depends heavily on the continuation of these trends.

China is investing in a comprehensive military modernization program that will provide the presence and capability to extend its power in Asia and beyond. China is instituting a development strategy with the intention to expand its capacity to exploit many of the technologies that the U.S. government considers to be "dual-use" sensitive—its investment in nuclear and space-system technologies is of particular concern. Although working toward closer relations with the United States on many levels, China still views the U.S. government as obstructing its emergence as a dominant regional and major global power. The recent $6.4 billion arms sales to Taiwan and the Dalai Lama's visit to the White House, both sensitive issues in China, are the latest example of the residual—but not fracturing—tensions in the relationship.

These challenges, in perspective, are not insurmountable. The U.S.-China relationship today can be characterized as part mutually dependent partnership, part economic competitor, and part global rival. No bilateral relationship is more important to global peace and security. The relationship's future trajectory is not pre-ordained but will depend on the behavior of both countries, including in S&T cooperation, over the next several years to decades. It is sufficient to say that, while still clouded with suspicions and disrupted by setbacks, the broader trends in the U.S.-China relationship today are fundamentally positive.

Singapore

Singapore has a land area of 272 square miles, a population under 5 million, and a GDP of about $234 billion. It is a tiny island nation that could hardly be expected to challenge the United States economically or militarily for the foreseeable future. Yet Singapore has developed an impressive S&T-driven, state-capitalist model of economic growth. It is investing in a range of dual-use technologies, including biotechnology, but its goals are transparent and generally directed toward making the country a first-world Asian center of scientific education and training and of high-technology services.

To sustain its current levels of economic growth, Singapore must find ways to expand its workforce. Unlike Japan, Singapore is substantially increasing non-Chinese immigration to unprecedented levels to meet its labor and leadership requirements. This helps the economy but also causes social tensions that the government is working to manage. Additionally, Singapore's welcoming policies increase concerns about the potential exploitation of this policy and growing S&T know-how by some of its less transparent Asian neighbors, international criminals, and global terrorist networks.

Singapore's relationship with the United States, at every level including security, is excellent. Singapore invests in its defense forces but not in a way that makes it a threat to any other country. If Singapore were a larger country, it would be an enviable model for the smart, competitive use of S&T strategic investment to drive economic growth. There are striking similarities between the innovation environments of China and Singapore.

India

India, the world's most populous democracy with more than 1 billion citizens, has wide internal cultural, social, and economic disparities. It is challenged by uneven domestic infrastructure, a relative scarcity of skilled labor, critical natural-resource shortages, major deficiencies in its agricultural sector, insufficient energy production, and growing concerns about terrorism and insurgency.

Despite these problems, India appears to be heading for strong S&T-driven economic growth and increasing status as a powerful regional leader over the next decade. The country has a functioning civil society, a growing middle class, and an educational system that, despite limited access to its 15 autonomous, elite Indian Institutes of Technology, produces a large body of university-educated engineers and scientists. India's government and private-sector S&T investment, along with the well-practiced partnerships and social networks that nurture S&T development, can propel strong economic growth. India is currently investing in nuclear energy, advanced IT systems, space and ocean exploration systems, and most particularly biotechnology.

India's S&T investment tracks sector-specific economic goals, but it does not constitute a comprehensive national strategy that targets the many problems facing this vast country, including wide disparities of income, uneven regional development, and natural-resource shortages (including water). S&T programs within selective economic sectors have strong leadership support and specific infrastructural capacity to advance their goals. But the country, as a whole, appears to lack a tradition of effective nation-wide and region-deep governance to develop a coherent, national S&T strategy.

Indian scholar Amit Pandya (2008, p. 276) writes:

> The political system in India is seriously fractured and its administrative system seriously compromised. Unlike Britain during its industrial revolution or China today, the Indian state is not capable of resolute response to the instabilities and resistance spawned by these rapid economic and social changes. Indian law enforcement and intelligence professionals note the seriously compromised capacity of the state to maintain law and order; they anticipate deterioration in the current chronic state of public disorder . . . Opportunistic and short-term political calculations render coherent long-term policy almost impossible.

India, like China, is a nuclear state. Its nuclear doctrine is oriented toward the threat from China, but, in reality, Pakistan represents the most urgent threat—as evidenced by India's continued conflicts with Pakistan in the Kashmir region. This troubled bilateral relationship seems unlikely to improve in the near- to mid-term and is a serious regional concern, because both states have nuclear weapons. U.S.-Indian relations have been improving since the later years of the George W. Bush administration. India's democratic political culture has been molded by its long and sometimes violent struggle for independence from Britain, its early post-independence decades of commitment to the non-aligned movement, and its need for self-reliance. The framework of relations between the United States and India will be positive on balance, but actual cooperation will most likely be achieved on an issue-by-issue basis.

Brazil

Brazil is a burgeoning democracy and an emerging economy with a growing but still modest S&T capability. It has progressed a long way since the era of military dictatorships, and its investment in military capability today is clearly a secondary priority. It has won its historic competition with Argentina and is recognized today as the leading democracy and economy of Latin America.

Brazil is advancing on international scales of S&T-proficiency that measure economic competitiveness. It has a growing middle class, strong manufacturing base, diversified business sector, energy independence, and an S&T strategy geared toward commercialization and economic expansion in areas of competitive advantage. It is devoting significant resources to nuclear technologies and cybernetics.

Within South America, Brazil is the leader in S&T and has one of the most advanced industrial sectors. With both the national will and substantial natural and financial resources, Brazil is creating an S&T innovation environment that promotes economic competitiveness. The country is a global leader in agricultural research, deep-sea oil production, and remote sensing. It has an abundance of natural resources, an extensive and growing domestic commercial market, a well-developed financial market, and a diversified and sophisticated business sector. Brazil's youthful population increasingly views higher education as essential to its professional success in the growing national and global economies—although Brazil still has a major shortfall in university students preparing for S&T careers.

Brazil faces some formidable obstacles in its efforts to develop a national innovation system. Its macroeconomic stability, efficiency of goods and labor markets, and institutional environment continue to be ranked poorly on international scales. It has major regional inequalities, a shortage of trained scientists and engineers in the workforce and in S&T, great disparity in income distribution across the country, persistent corruption, and a chronic private-sector reluctance to fund and engage in R&D. These problems have hampered Brazil's efforts to achieve its bold economic goals, and will continue to do so over the next several years.

Japan

Japan is an advanced S&T state and is investing in numerous high-end technologies such as space transponders, new-generation supercomputers, fast breeder reactors, and EARTH observation and ocean explorations systems. It has an impressive national innovation system, including privately funded state-of-the-art laboratories.

Japan has made some progress in turning around its economy after a decline in the 1990s, despite a fractured and seemingly disintegrating political party system. But the country still faces formidable political, economic, and cultural obstacles in achieving its bold targets for economic growth over the next 5 to 10 years. Japan has an aging industrial base, a declining population, and a cultural resistance to the levels of immigration it needs to boost economic growth. Japan, as a matter of priority, needs to restructure its export industries to place greater emphasis on technology products and services. To effectively deal with these chronic problems, Japanese leadership must address the deep-seated deficiencies of its national party system.

Japan has growing regional security concerns, especially with regard to North Korea. It will invest in modernization of its defense forces, but will continue to rely for the most part on its longstanding security pact with the United States.

Russia

This comparative study puts in relief Russia's slow integration into the global economy. A major nuclear power, it has the clear potential for strong economic growth over the next decade, but several constraints are likely to prevent this from happening. Russia urgently needs to invest in its people by reviving the education and healthcare systems. Russia's population is aging, declining, and becoming less healthy. To spur significant economic growth, Moscow must invest in an energy sector on which it already depends too heavily, diversify the economy, build up its primitive banking sector, welcome the international community, and move aggressively to contain pervasive corruption and criminal activity.

Russia continues to be advanced in narrow S&T capabilities, but it does not have a coherent S&T investment strategy. Leadership commitment is half-hearted, and capacity is limited. The focus of the current top-down decision-making environment is on such issues as nuclear power and space systems, not on a comprehensive S&T-based plan to promote broad-based economic growth. Funding is inadequate. Russia is a long way from establishing a credible national innovation ecosystem.

Russia devotes disproportionate resources to its global intelligence activities and to restoring some of its reduced military capabilities. The combination of its authoritarian leadership, its limited practice with democracy, and its guarded economic prospects raise concern about its capacity to boost investment in dual-use technologies for military purposes as a hedge against its declining global stature. This is not an evidence-based prediction but merely a notional depiction of a possible alarming turn if Russia's economic climate does not adopt a more transparent economic model with stronger links to the global economy.

Russia has considerable S&T proficiency and ambitious goals, but it has diminished capacity and limited leadership support—governance problems, again—in a top-down political decision-making process. Its nuclear arsenal, of course, and its preoccupation with investment in enhanced military capability will remain matters of considerable concern for the United States.

FINDINGS AND RECOMMENDATIONS

Finding 9-1. The global S&T revolution represents a major, 21st-century challenge to the United States. This challenge should be elevated to the first tier of U.S. national security priorities, even though this is a tall order for a decentralized democratic government that has never had a comprehensive national S&T strategy. The U.S. innovation system, as good as it is, will require substantial new investment over the next decade to meet the unprecedented economic and security challenges of the global S&T revolution.

Recommendation 9-1. The U.S. government should assess, as a matter of urgency, the national security implications of the continuing global S&T revolution and the global dispersion of R&D. It should evaluate the impact of the decline in U.S. academic competitiveness at the primary and secondary levels, as pointed out in the 2007 report *Rising Above the Gathering Storm*, especially with regard to the sciences. Equally important, the assessment should seek mechanisms for sustainable U.S. government collaboration with the international community to uncover and exploit potential scientific and technological breakthroughs, wherever they occur, and to contain whatever threats they may portend.

Recommendation 9-2. The U.S. intelligence community should provide continuous strategic analysis of global S&T developments to the U.S. government, and it should significantly boost its efforts to do this at both the departmental level and for the national intelligence estimate process led by the Director of National Intelligence. To achieve this, the intelligence community should employ the most advanced and imaginative models for interdisciplinary analyses that utilize broad and deep collaborations with other U.S. government agencies, academia, the private sector, and foreign sources of information and expertise.

Finding 9-2. The rapid advancement of technology and global dispersion of R&D are enabling economic competitors of the United States, as well as its real or potential military adversaries including non-state actors, to boost their capabilities and to exploit emerging and disruptive technologies for asymmetric operations. The less transparent world of military and intelligence S&T programs, as well as the insidious proliferation of dual-use technologies, will increasingly require the close engagement of U.S. intelligence agencies in collaborative operations and information-sharing agreements with foreign governments and external sources of critical expertise wherever such expertise may reside.

Recommendation 9-3. The top leadership of the U.S. intelligence community should renew its commitment to build a global S&T intelligence (S&TI) warning capability to prevent or contain technological surprises. It should include state-of-the-art collection and the analytic capabilities and global collaborations needed to monitor fast-moving foreign technology developments. This initiative will require sustained leadership, the allocation of scientific and multidisciplinary resources across intelligence agencies, and working relationships with U.S. government agencies, the scientific community, foreign governments, and other sources of outside expertise.

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10

Recommended Strategies for the United States

INTRODUCTION

The committee's survey of Japan, Brazil, Russia, India, China, and Singapore, or JBRICS, has it made abundantly clear that both developed and developing countries are actively seeking to expand their science, technology, research, and engineering capacities to enhance their national science and technology (S&T) innovation environments, much along the lines of that in the United States. National efforts in the JBRICS countries and others are influenced by the ever-increasing globalization of production, research and development (R&D), and basic science as universities and multinational corporations expand their global presences. Thus, what started as the international expansion of manufacturing through outsourcing has transformed naturally into the globalization of R&D. The historic national progression up the economic ladder seen so often in developing countries—from assembly, to design, to creation—is now being played out in the increasingly globally connected S&T community as countries invest in their areas of greatest S&T competence.

In addition to the effects of globalization and to the realization of diminishing global resources (e.g., water, minerals, energy, space), critical mainstays of the United States' S&T asset base are becoming increasingly susceptible to disruptive innovations. A prime example is the semiconductor industry, which has been a principal driver of information technology (IT)-sector technologies from supercomputers to the Internet that serve the interests of U.S. national security and economic competitiveness. The physical limits to transistor scaling and form-factor reductions require new, disruptive technological innovations for continued miniaturization of electronics. Countries that are first to create them will gain advantage or possibly even dominance in the IT sector of the future.

21st-CENTURY GLOBAL SCIENCE AND TECHNOLOGY INNOVATION ENVIRONMENT

During the second half of the 20th century the United States had the most enviable national S&T innovation environment worldwide. Providing opportunities for and investing in innovation at the level of individuals, national corporations/organizations, and national laboratories, with high levels of government support (e.g., in areas such as security, health, education, research, and S&T infrastructure), proved to be a very successful approach. America's entrepreneurial culture aligned with financial incentives, the availability of capital, and strong patent laws to spur innovation. Critical to the successes of this remarkable period were the recruitment of top global talent to the United States, the building of a world-leading research infrastructure, and the growth of a robust economy underpinned by successful technology developments. A half century ago this unbeatable asset base led to U.S. dominance in the global S&T community. Many countries have tried to emulate the U.S. system, but only a few have partially succeeded.

However, over the past half-century the foundation of the U.S. S&T asset base has eroded relative to those of other countries in significant ways. Now there are other major global players in an increasingly integrated global S&T arena, and more are expected to arrive. U.S. national corporations have all given way to multinationals with multiple allegiances. Within the JBRICS countries, planners are steadily upgrading higher education and S&T research capabilities, and support for connections to industry and innovation is increasing. Although the United States continues its leadership in areas, it is by ever-decreasing margins. Top talent from around the world, who once would have come to the United States for higher education or for postdoctoral or permanent positions in S&T, are being recruited aggressively to other countries with attractive salaries, high-quality research infrastructures, a frontier vision of exciting prospects, and a welcoming attitude. The United States, on the other hand, discourages or simply prevents the emigration of top talent. With more than 95 percent of the world's talent residing outside the United States, recruiting internationally is essential, and will remain so even if our domestic compulsory education system becomes enviable. The research infrastructures in Singapore and throughout China, although not yet among the best overall, are developing rapidly. They are being built by both multinational corporations and national investments. Top facilities, competitive with those in the United States, are also being located in the other JBRICS countries studied.

Leadership in the more effective countries is looking beyond the national, U.S.-type S&T innovation environment of the past to create global S&T innovation environments. Such environments extend the national environments by embracing partnerships and collaborations of global enterprises, the benefits derived from open S&T environment created by global communications, and the importance of S&T innovation that is driven top-down by government as well as bottom-up by individuals, academia, and industry.

Finding 10-1. The 20th-century national S&T innovation environment that has been a hallmark of the United States since World War II, and the model for the world, is evolving into a new 21st-century global S&T innovation environment in which R&D talent, financial resources, and manufacturing facilitated by global communications are geographically dispersed and globally sourced.

Top-down innovation environments are led by governments that provide the large investments required for facilities and capabilities that the private sector will not support (e.g., national electricity grid, large research infrastructure, education). Governments can initiate work on the great problems (e.g., clean energy, climate change, pandemics); develop human resources from the global talent pool through education, immigration policies, and recruitment strategies; and ensure the building of necessary top-class facilities.

Bottom-up innovation environments are led by individuals and organizations with independent leaders who engage in the inventive ideas, scientific discovery, engineering creation, and innovative implementations that produce products and services that are commercially viable and globally competitive. Governments can actively encourage bottom-up innovation with efficient intellectual property (IP) policies, transparent and consistent regulations, and tax laws favorable to R&D investment.

Finding 10-2. The S&T innovation environments in the more successful countries possess both top-down innovation environments led by government and bottom-up innovation environments led by individuals and organizations. Of the countries studied, China and Singapore are furthest along in this direction and are progressing toward global innovation environments. The likelihood of their continued, substantial progress is high. Singapore uses its small size and top-down planning to engage the global community, recruit international scholars, provide unique facilities, and offer extended funding commitments to top R&D talent. China's top-down strategy, which involves the central government plus the provincial and major city governments, uses its vast market opportunity to engage multinational corporations in meeting its goals. Its policies seek to enhance the absorption, assimilation, and re-innovation of imported technologies.

Finding 10-3. Although of vastly different sizes, China and Singapore have similar S&T strategies. Both countries invest heavily in top-down higher education and research, create research parks near universities, and promote international collaborations. Both heavily subsidize study abroad for Ph.D. students. Both recruit talent globally, using high-quality facilities and research support as incentives. Both move quickly and with authority when decisions are made. Both utilize strong top-down leadership to adapt their cultures to facilitate their S&T goals. Both will find ways to achieve their goals, even if later than planned.

Singapore has done very well in realizing its five-year goals, which indicates that its national goals for defense, renewable energy, climate change and sustainability, urbanization, infectious disease management, and food security and water supplies are realistic. If the past is the prologue, China will find a way to achieve its S&T aspirations, although probably not within the stated timelines, except for those related to its highest, national security priorities. Key obstacles for China are likely to be its inadequate educational system, insufficient numbers of qualified domestic S&T personnel, a bureaucratic scientific and market environment that is systemically prone to corruption, continuing dependence on a high economic growth rate, continued reliance on the acquiescence by multinationals and foreign governments to invest in the country and transfer their technology, and a highly centralized political system that is opaque to outside influences. The latter point contrasts with Singapore, which although highly centralized, has recruited outside assistance throughout its planning processes. China's anti-monopoly law compels multinational corporations to transfer proprietary technology to their Chinese subsidiaries, and its IP regime is poorly regarded. These could be substantial self-inflicted wounds if multinationals become reluctant to locate cutting-edge R&D facilities in China, focusing instead on application-specific, mostly development facilities.

Japan has restructured its university system to facilitate faculty participation in its S&T innovation environment. But after about 20 years of reforming its top-down and bottom-up innovation environments, progress in reform has been slow, possibly because of cultural issues that limit recruitment of talent, restrict immigration, discourage women in the workforce, and create an opaque leadership. Its decreasing population and decreasing student interest in S&T may also be factors. Little change in Japan's S&T innovation environment can be expected in the near term, although a downward shift in its relative strength compared to other countries is more likely than an upward shift. Nonetheless, if the value attributed to multinational corporations in China and India is discounted, Japan will remain the strongest competitor of the United States in S&T for the next decade. The United States should position itself to capture value from Japan's R&D efforts in the niche areas of energy, food and resource security, and environmental protection.

Following the South Korean model, Brazil is determined to become a world power in agricultural research, deep-sea oil production, and remote sensing based on its S&T innovation environment and its careful, conservative planning and investing. Its top-down S&T innovation environment includes clear plans and investments. Most research is undertaken in universities, but the country has not yet developed adequate mechanisms for technology transfer to industry, which is the principal voice and financer for S&T investments. Brazil supports economic development in business through tax revenues, rather than debt. In many states, including Sao Paulo, 1 percent of corporate revenues is collected and pooled for re-investment in industrial development. The shortages of workers and students in S&T, the absence of research and research opportunities in industry and consequently the absence of university-industry research collaborations, the low efficiency of goods and labor markets, and the disconnect within the national S&T community itself hamper the development of Brazil's bottom-up S&T innovation environment. These limitations will likely be addressed over time, leading to a steady, although not rapid, strengthening of a global S&T innovation environment. A significant change in Brazil's S&T innovation environment and global leadership position is not expected over the next three to five years.

Through its national S&T innovation environment, India's goal is to become a self-reliant, developed country by 2020. Attainment of that goal is doubtful. India's strengths are its large domestic market, young and growing population optimistic about the future, private sector with experience in market institutions, well-developed legal and financial systems, and critical mass of English-speaking S&T and other professionals. India now solicits and encourages foreign participation in its industries. India hosts 150 of the Fortune 500 companies, and expatriates are returning to contribute to India's development. However, India has no apparent public strategy beyond its five-year plans. Its progress has been steady, with its most significant, top-down S&T commitments being directed toward space and nuclear energy and driven by fear of technology denial by foreign countries. Indian industry is not sufficiently engaged in the S&T innovation environment; it supports only 25 percent of the nation's research expenditures and does not proactively support basic research. In turn, academic initiations value basic research much more than applied research. National goals to increase research expenditures from 0.9 percent to 2 percent of GDP, and education expenditures from 4 percent to 6 percent of GDP, are unlikely to be met within five years. Widespread poverty, rapid population growth, deficient infrastructure, and insufficient high-quality, higher education opportunities are persistent problems unlikely to be solved in the near to mid terms. Although continued steady progress toward a global S&T innovation environment in India is expected, these major problems impede the development of a broad-based, bottom-up S&T innovation environment in the short term. It should be noted, however, that democratic institutions and processes may be inherently slow and inefficient in the short term, but they are inherently larger and more stable in the long term. India is expected to become a strong S&T player in the medium to long term.

Russia is the least likely of the JBRICS countries to develop a global S&T innovation environment within 5 years, and most likely not within 10 years, even though the country has a strong top-down national S&T innovation environment centered on space and energy resources, including its massive expansion of nuclear power. It has no bottom-up innovation environment of significance. For the longer term, significant improvements will require profound policy and cultural changes. Russian universities lack a robust research culture, which limits the nurturing of innovators and the engagement of universities with industry in the development and commercialization of innovations. Traditionally, engagement with industry has not been considered an appropriate activity for university faculty. The Russian government is the principal consumer of its national products. This isolation is further reflected in the lack of global engagement and collaboration in the Russian research community and of international participation and investment. Of the six countries examined, corruption, bureaucracy, the lack of political transparency, and the breakdown in the rule of law stood out in Russia as discouraging foreign investment and the pursuit of innovation by the private sector.

Finding 10-4. Little change is expected in Japan's sophisticated innovation environment in the near term, although over time a downward shift relative to other countries is more likely to occur than an upward shift. However, its current position as having the second-strongest S&T innovation environment after the United States ensures a continued strong position over the decade even with little change. A modest change in Brazil's innovation environment is expected within the next three to five years, although it will steadily improve over time. Strengthening of its S&T innovation environment must be preceded by overcoming shortages in S&T students and workforce and the paucity of industry research. India's innovation environment has both substantial strengths and weaknesses. A modest change is expected in the next three to five years; substantial progress in strengthening its innovation environment is constrained by political (institutional), societal, and financial realities.

Finding 10-5. Russia will not develop a global innovation environment, and its national innovation environment will not develop significantly within the next 10 years. Its strong top-down innovation environment will target traditional areas of current strength (energy, space, nuclear, military).

Finding 10-6. The presence of multinational corporations provides mechanisms for transfer of technology and IP into foreign domestic markets and governments. China, for instance, requires transfer of technology as a condition for doing business with the government. IP can also simply leak through permeable processes—even if illegal. The increasing presence and growth of multinational corporations abroad facilitates the transfer of technologies into countries from which they did not originate.

Recommendation 10-1. Because a successful global S&T innovation environment portends future prosperity and security for all countries, monitoring the transformation from a national to a global S&T innovation environment should be undertaken on a regular basis for the United States and all countries of interest. Because this transformation can take place before a national S&T environment is fully developed, monitoring should be conducted independent of a country's current achievement.

Recommendation 10-2. The transfer of intellectual property by multinational corporations into domestic companies through S&T activities should be monitored in key countries, particularly India and China. The United States could join with Japan, and possibly the European Union, to establish a united front against such practices.

Recommendation 10-3. The United States should assess its own preparation for, and transformation to, a successful global S&T innovation environment to ensure that it remains in a preeminent S&T position for continued prosperity and national security. Specific areas for assessment should include global exchanges in education and R&D talent, international as well as national recruitment of R&D talent, multinational corporate collaborations, and public policies that facilitate or restrain the leadership of the United States in global S&T innovation.

INDICATORS OF SCIENCE AND TECHNOLOGY ACHIEVEMENT ARE COUNTRY SPECIFIC

Although sometimes useful, traditional supply and output metrics alone are insufficient to predict future S&T development in a country and may mask other important trends. The roles of knowledge markets and international networks, intellectual assets for value creation, emergence of new players in S&T (social entrepreneurs, nongovernmental organizations, user groups, new financial incentives and sources of investment, etc.), and increasing national priority accorded to innovation in economic strategy (as well as S&T) impact the future of S&T in all countries. Innovation systems are becoming ever more complex and international as well as national in scope.

Consider for example, patent filings as a measure of S&T innovation. Patents for work in developing countries, such as Brazil, by multinational corporations are often filed in other countries, such as the United States. In this case a patent filing count by country gives the United States credit for a Brazilian innovation. Interpretation of patent filing numbers also unduly emphasizes technologies for which patents are common and bypasses technologies for which they are not. No measure of technology value is provided in either case. Publications are similarly untrustworthy as a blanket measure of S&T strength and potential growth. Aside from the real concerns about uneven and untrustworthy publication standards, various R&D communities also use and value journal and conference publications differently.

One technology-specific indicator that assures quality of work without additional expert review is the identification of forums within a discipline in which the best work is presented in open meetings. For instance, in the semiconductor arena (involving design and production of integrated circuits for computers, cell phones, and medical applications) the annual "International Solid State Circuits Conference" (ISSCC) presents about 200 papers, split evenly between industry and academia (Americas 40 percent, Far East 35 percent, and Europe 25 percent). Acceptance of a paper for the ISSCC ranks as the highest recognition of research impact and quality. (In 2009 Hong Kong and Mainland China presented 2 papers each, Singapore and India 1 paper each, Russia and Brazil 0 papers, Japan 33 papers, and the United States 73 papers.) This technology-specific indicator gives a relatively accurate picture of the S&T standing of these countries in this specific technology. Other international forums, coupling rigorous review and selection methods spanning an S&T area, may provide similarly meaningful measures of national prominence and global standing.

Nontraditional indicators of the S&T innovation environment emerge from the cultural context of a country and can often be principal drivers or anchors for the future S&T innovation environment in the country. Examples of such indicators are as follows: encouragement of women in the S&T workforce, welcoming immigration policies for S&T workers, promotion of collaborations between universities and industry, independence of innovators to create and profit from their work, wealth inequality and social instability as rate limiters, influence of crime and corruption, level of governmental control over the bottom-up innovation environment, attractiveness for foreign investment, exodus or influx of domestic and international talent, international engagement, and population decline or expansion.

Japan has the second best S&T innovation system in the world and is host to large, well-funded research laboratories established by private industry. They are addressing the weak engagement of universities in S&T value creation. Japan's slow progress to date in developing a global S&T innovation environment appears largely related to issues flagged by nontraditional indicators. Brazil and India are working through similar issues, and Russia's limited prospects reflect them.

Indicators of Russian progress in S&T beyond the short term should include monitoring the percentage of S&T funded privately versus by government; the change in direct foreign S&T investment within Russia; the age, qualification, and field of S&T personnel; the change in the entry of Russian commercial products into global markets; the changes in the numbers of foreign researchers entering Russia and of Russians leaving Russia; and the change in the national stature of Russian S&T personnel.

The rate and scale of cultural changes that China has implemented to build its S&T innovation environment are notable, especially when compared to the other countries studied. Continued improvements in its S&T innovation environment depend on its continued facilitation of cultural changes, making cultural change an important nontraditional indicator when evaluating China's progress. Singapore's challenge lies in balancing its tightly controlled culture with the influx of foreign workers (31 percent of the total employment), new ideas, a more highly educated citizenry, and the potential for terrorist attacks.

Finding 10-7. Country-specific, traditional and nontraditional indicators can provide a meaningful measure of national S&T strength and prospects for future change. No single set of common indicators across all countries was found to provide such a measure. Nontraditional indicators are country-specific and are essential to understanding each country's S&T innovation environment and especially to predicting future change.

Finding 10-8. Nontraditional national indicators of the S&T innovation environment include those that emerge from the cultural context of a country and impact the future S&T innovation environment of the country. These indicators are especially important for predicting future change in the S&T innovation environment. The cultural contexts of Brazil, Japan, India, and Russia have hindered their S&T innovation developments and will continue to do so for at least the near term and likely longer. Singapore has taken advantage of its small size and highly centralized government to launch ambitious initiatives and instigate changes rapidly. Similarly, China has used its authoritarian political system to define a national S&T plan.

Finding 10-9. When a country can facilitate the cultural changes needed for its S&T innovation environment goals, its capability to achieve them increases significantly. It is among the best indicators of future success. China and Singapore have demonstrated high capability to change cultural norms to achieve their S&T goals, although encouraging individual creativity and independence remains an unrealized need for both of them. Brazil has demonstrated the capability to change cultural norms. India has demonstrated culture changes also, but its democratic society imposes limitations on its actions. Japan has demonstrated less of a capability, and Russia the least capability, for cultural change among the countries.

Recommendation 10-4. For each country of interest, the United States should identify country-specific measures of S&T innovation environments, including nontraditional indicators that are appropriate for targeted technologies and developments. The United States should monitor each country's capacity to facilitate the cultural changes needed to achieve its global S&T innovation goals. These indicators are especially important for predicting future changes in S&T innovation environments.

S&T TALENT IN HIGH DEMAND IN ALL COUNTRIES

A global competition for S&T talent is underway. Countries are using a variety of strategies to recruit talent, including luring expatriates and experts from abroad with superior financial support, offering top working conditions and research facilities, expanding higher education opportunities to attract internal and external students, and recruiting multinational companies to open S&T facilities. Each country understands that talent is the coin of the S&T realm, although they differ in their effectiveness in satisfying the need.

China and Singapore offer exciting opportunities, incentives for S&T careers, superior and specialized facilities, top infrastructure, and financial supports to attract talent from abroad and at home. With an eye on the long term, they are investing heavily in doctoral S&T education, key universities, and research parks at universities. Multinational corporations are also engaged in both countries, even if they are attracted to China and Singapore for different reasons. They are attracted to China by access to the very large marketplace and talent pool, despite the open risk of losing intellectual property and technology acquisition. In comparison, Singapore offers an exceptional S&T infrastructure, laws and a culture that are friendly to global business, political stability, lack of corruption, an English-speaking environment, and relatively high salaries. As a consequence, however, multinational corporate research experiences are educating their domestic workforces.

Japan faces reduced interest in S&T by Japanese students, discouragement of women in the workforce, a declining and aging population, and a national distrust of immigration. These challenging realities slow expansion of the talent pool. India plans to expand educational opportunities at universities, but for financial reasons cannot do so on a large scale for the near term. Expatriates are returning to India, and substantial numbers of multinational companies are welcome there. However, the near-term growth of the talent pool for S&T through education and international recruitment is positive but limited. Brazil currently has an S&T talent shortage, relatively low interest in S&T in its university students, a disconnect between industry and universities, and little research opportunity in industry. No significant immigration of S&T talent occurs. These circumstances, along with a conservative development philosophy, indicate that the S&T talent shortage in Brazil will continue for at least the next five years. Russia is experiencing an aging S&T workforce, a decreasing national population, an exodus of S&T talent, and low immigration rates. Although its higher education is superior, it remains disconnected from research and S&T innovation in industry. Its older R&D talent pool serves its current S&T strengths (space, energy, nuclear, military) but displays low prospects for assuming leadership in other recent technologies.

Finding 10-10. Each of the six countries studied understands the value of top talent in its S&T innovation environment, but only China and Singapore have been able to greatly expand S&T education nationally, although China remains a work in progress for both quality and the quantity of higher education opportunities. China, Singapore, and India actively recruit multinational corporations to bring talent from abroad, and create opportunities for talent from abroad to work in their country using recruiting tools like state-of-the-art research facilities, competitive salaries, and research opportunities.

Recommendation 10-5. The most successful global S&T innovation environments will recruit S&T talent into attractive positions with excellent facilities and research support. The United States should track the quality and availability of research facilities and research support as a significant indicator of any country's attractiveness to the world's S&T talent.

Recommendation 10-6. The United States should continue to gauge the efficiency of research, measured by the effective uses of research talent and research facilities, which portends the future of a county's innovation environment. Efficiency ultimately guides the use of research talent and facilities. For instance, the monitoring of non-research responsibilities of scientists (such as administration and proposal writing) and the quality of research infrastructure could be incorporated into measures of efficiency. Highly efficient S&T systems support the most attractive research careers for talented S&T contributors.

Appendixes

Appendix A

Biographical Sketches of Committee Members

C. D. (Dan) Mote, Jr. *(Chair, NAE)* is president of the University of Maryland and Glenn L. Martin Institute Professor of Engineering. Under his leadership, academic and research programs at the university have flourished. In 2009, the university was ranked 18th among public research universities, up from 30th in 1998. Dr. Mote is a leader in the national dialogue on higher education, and his analyses of shifting funding models have been featured in local and national media. He has testified about major educational issues before Congress, representing the university and higher education associations on the problem of visa barriers for international students and scholars and on deemed export control issues. He has served and currently serves on several National Research Council committees that work to identify challenges to U.S. leadership in key areas of science and technology, including the committee that wrote the *Rising Above the Gathering Storm* report. Dr. Mote is currently co-chair on the NAS Government-University-Industry-Research Roundtable and a member of the Committee on Science, Engineering, and Public Policy (COSEPUP). He is also a member of the Steering Committee of the Energy Security Innovation and Sustainability Initiative, an activity of the Council on Competitiveness. He served as vice chair of the Department of Defense Basic Research Committee and was a member of the Academy of Arts and Sciences ARISE panel that produced *Advancing Research in Science and Engineering: Investing in Early-Career Scientists and High-Risk, High-Reward Research*. In 2004 he was appointed a founding member of the National Security Higher Education Advisory Board. Dr. Mote is a member of the Council and treasurer of the National Academy of Engineering (NAE). He serves on the board of directors of the Greater Washington Board of Trade and the Federal City Council.

Prior to assuming the presidency at the University of Maryland, Dr. Mote was a member of the University of California (UC), Berkeley faculty for 31 years. From 1991 to 1998, he was vice chancellor at UC Berkeley, held an endowed chair in mechanical systems, and was president of the UC Berkeley Foundation. He led a comprehensive capital campaign for UC Berkeley that raised $1.4 billion. He earlier served as chair of UC Berkeley's Department of Mechanical Engineering and led the department to its number one ranking in the National Research Council review of graduate program effectiveness.

Dr. Mote is internationally recognized for his research on the dynamics of gyroscopic systems and the biomechanics of snow skiing, and he has produced more than 300 publications. He holds patents in the United States, Norway, Finland, and Sweden, and he has mentored 58 Ph.D. students. Dr. Mote has received numerous awards and honors, including the Humboldt Prize awarded by the Federal Republic of Germany. He is a recipient of the Berkeley citation, an award from UC Berkeley similar to the honorary doctorate, and he was named Distinguished

Engineering Alumnus. He has received three honorary doctorates. Dr. Mote is a fellow of the American Academy of the Arts and Sciences, the American Association for the Advancement of Science, the Acoustical Society of America, and the International Academy of Wood Science, and he holds honorary membership in the American Society of Mechanical Engineers (ASME). He received the 2005 J.P. Den Hartog award from the ASME International Technical Committee on Vibration and Sound to honor his lifelong contribution to the teaching and/or practice of vibration engineering. In 2005 he received the Founders Award from the NAE in recognition of his comprehensive body of work on the dynamics of moving flexible structures and his leadership in academia. He earned B.S., M.S., and Ph.D. degrees in mechanical engineering from UC Berkeley.

John Gannon *(Vice Chair)* is vice president for Global Analysis, a line of business within BAE Systems Information Technology. Prior to joining BAE Systems, Dr. Gannon served as staff director of the House Homeland Security Committee, the first new committee established by Congress in more than 30 years. In 2002-2003, he was a team leader in the White House's Transitional Planning Office for the Department of Homeland Security. He served previously in the senior-most analytic positions in the intelligence community, including as the Central Intelligence Agency's (CIA's) director of European analysis, deputy director for intelligence, chairman of the National Intelligence Council, and assistant director of central intelligence for analysis and production. In the private sector, he developed the analytic workforce for Intellibridge Corporation, a web-based provider of outsourced analysis for government and corporate clients. Dr. Gannon served as a naval officer in Southeast Asia and later in several Naval Reserve commands, retiring as a captain. He holds a bachelor's degree from Holy Cross College in Worcester, Massachusetts, and master's and doctorate degrees from Washington University in St. Louis, Missouri. He is an adjunct professor in the National Security Studies Program at Georgetown University.

Rakesh Agrawal *(NAE)* is a Microsoft technical fellow and heads the Search Labs in Microsoft Research, where he is leading development of a next-generation search engine. He is a member of the National Academy of Engineering, a fellow of the Association for Computing Machinery (ACM), and a fellow of IEEE. He is the recipient of the first ACM-SIGKDD Innovation Award, ACM-SIGKDD Edgar F. Codd Innovations Award, ACM-SIGMOD Test of Time Award, VLDB Most Influential Paper Award, IEEE-ICDE Most Influential Paper Award, and Computerworld First Horizon Award. In 2003, he was named one of *Scientific American*'s 50 top scientists and technologists. Prior to joining Microsoft in March 2006, Dr. Agrawal was an IBM fellow and led the Quest group at the IBM Almaden Research Center. Earlier, he was at Bell Laboratories from 1983 to 1989. He also worked for three years at Bharat Heavy Electricals, Ltd. in India. Dr. Agrawal is well known for developing fundamental data-mining concepts and technologies and pioneering key concepts in data privacy, including Hippocratic database, sovereign information sharing, and privacy-preserving data mining. IBM's commercial data-mining project, Intelligent Miner, grew out of his work. His research has been incorporated into other IBM products, including DB2 Mining Extender, DB2 OLAP Server, and WebSphere Commerce Server and has influenced several other commercial and academic products, prototypes, and applications. His other technical contributions include the Polyglot object-oriented type system, Alert active database system, Ode (Object database and environment), Alpha (extension of relational databases with generalized transitive closure), nest distributed system, transaction management, and database machines. Dr. Agrawal has been granted more than 60 patents. He has published more than 150 research papers, many of them considered seminal. He has written the first- as well as second-highest cited of all papers in the fields of databases and data mining (13th and 15th most cited across all computer science as of February 2007 in CiteSeer). His papers have been cited more than 6,500 times, with more than 15 of them receiving more than 100 citations each, making him the most-cited author in the field of database systems. His work has been featured in the *New York Times Year in Review*, the *New York Times* science section, and several other publications. He received M.S. and Ph.D. degrees in computer science from the University of Wisconsin-Madison in 1983. He also holds a B.E. in electronics and communication engineering from IIT-Roorkee and a two-year postgraduate diploma in industrial engineering from the National Institute of Industrial Engineering (NITIE), Bombay.

Robert Brodersen *(NAE)* is an emeritus professor in the Electrical Engineering and Computer Science Department of the University of California, Berkeley. He is currently chairman of two companies that he co-founded with former students: SiBEAM, which provides multi-gigabit wireless transmission service using 60 GHz CMOS, and BEEcube, which produces field-programmable gate array computing and emulation platforms. Dr. Brodersen is also a co-founder of Atheros Communications, a supplier of WiFi chips and systems, and Adaptrum, a company dedicated to exploiting radio “white space” opportunities. He has won best paper awards for a number of journal and conference papers in the areas of integrated circuit design, computer aided design (CAD), and communications, including the IEEE Baker Award for Best Paper in the IEEE transactions and the IEEE Morris Liebmann Best Paper Award. In 1982 he became a fellow of the IEEE, and in 1988 he was elected to be member of the National Academy of Engineering. Dr. Brodersen has been recognized extensively for his work and is the recipient of the IEEE Technical Achievement Awards in both the Circuits and Systems Society and the Signal Processing Society, the IEEE Solid State Circuits Award, an IEEE Millennium Award from the Circuits and Systems Society, and the Golden Jubilee Award. In 2001 he was awarded the Lewis Winner Award for outstanding paper of the IEEE International Solid-State Circuits Conference, and in 2005 he received the Jack Raper Outstanding Paper Award for the same conference. In 2006 he was a co-recipient of the Jack Neubauer Award for best paper of the year in the Vehicular Technology Society transactions. In 1999 Dr. Brodersen received an honorary doctorate from the University of Lund in Sweden. He received his Ph.D. in electrical engineering from Massachusetts Institute of Technology in 1972.

Daniel T. Chiu is a professor of chemistry at the University of Washington, Seattle. His research focuses on the information processing and encoding methods of complex biological systems using tools that combine ultrasensitive laser-based detection and manipulation methodologies with micro- and nano-fabrication techniques. Dr. Chiu is currently a member of the University of Washington’s Center for Nanotechnology and Neurobiology and Behavior Program. He is the recipient of numerous awards and honors, including the McKnight Technological Innovations in Neuroscience Award, the National Institutes of Health Cutting-Edge Technology in Basic Research Award, the National Science Foundation Career Award, and the Research Corporation’s Research Innovation Award. He was named a Keck Distinguished Young Scholar in Biomedical Research in 2003 and an Alfred P. Sloan fellow in 2005. Dr. Chiu is the author of more than 100 publications and has issued 25 patents in the United States and abroad. He obtained a B.A. in neurobiology and a B.S. in chemistry at the University of California, Berkeley in 1993, and a Ph.D. in chemistry from Stanford University in 1998. He completed postdoctoral research at Harvard University.

Jaqueline Fletcher is a Regents’ professor of plant pathology and director of the National Institute for Microbial Forensics & Food and Agricultural Biosecurity at Oklahoma State University. Her research interests center on prokaryotic plant pathogens, including wall-less bacteria (spiroplasmas and phytoplasmas) and bacteria with walls. Both of these groups provide exciting avenues for evaluation of disease processes, transmission factors, host resistance, and the genetic mechanisms that control these processes. She is currently involved in biosecurity work with the National Bioforensics Center at the Department of Homeland Security, the Biological Sciences Experts’ Group at the National Intelligence Council, the One Health National Initiative, and the Inter-Agency Working Group on Citrus Variegated Chlorosis. She is also chair of the American Phytopathological Society (APS) Food Safety Interest Group, the Microbial Forensics Interest Community, and the APS Councilors’ Forum. She has been an American Association for the Advancement of Science fellow (2007) and an American Phytopathological Society fellow (2005), and she is the recipient of the Sigma Xi Lectureship Award. Dr. Fletcher has a Ph.D. in plant pathology from Texas A&M University and an M.S. in botany from the University of Montana.

Paul C. Gailey is a physicist currently serving as senior science advisor to the Fetzer Institute and director of research for the Fetzer-Franklin Fund, a nonprofit international science research program aimed at identifying, funding, and providing intellectual support for advanced projects in cognition and consciousness. He has worked in the areas of electromagnetic theory, nonlinear dynamics, and random processes particularly as they relate to living systems. During his career, Dr. Gailey served as a research scientist for the U.S. Environmental Protection Agency, a research director at Oak Ridge National Laboratory, and associate professor of physics and astronomy at Ohio University. During the past 10 years, he has served variously as consultant, vice president, and senior advisor to the Fetzer Institute, working to promote a deeper cultural dialogue on science and spirituality—particularly regarding how our conception of science interacts with human values and our sense of meaning. He earned his Ph.D. in electrical engineering from the University of Utah and his M.S. and B.S. degrees in physics from the University of North Carolina at Chapel Hill.

Hendrik F. Hamann is currently a research manager for photonics and thermal physics in the Physical Sciences Department at IBM's T.J. Watson Research Center. In 1995 he joined JILA (a joint institute between the University of Colorado and the National Institute of Standards and Technology) as a research associate in Boulder, Colorado. During his tenure at JILA he developed novel near-field optical microscopes to study single molecules at high spatial resolution. Since 2001 he has been leading the thermal physics program in IBM Research, first as a research staff member and currently as a research manager. His current research interest includes nanoscale heat transfer as well as thermal and energy management of computing systems. His responsibilities include strategy work for science and technology in IBM. He has authored and co-authored more than 30 peer-reviewed scientific papers and holds more than 30 patents and more than 25 pending patent applications. Dr. Hamann is an IBM master inventor, has won several major IBM awards, and has been a Finalist of the New York Academy of Science Innovation in Industry Awards. He has served on several governmental committees and is an industrial advisor to several universities. He is a member of the American Physical Society (APS), Optical Society of America (OSA), and IEEE.

Daniel E. Hastings is dean for undergraduate education and a professor of aeronautics and astronautics and engineering systems at the Massachusetts Institute of Technology (MIT). As professor of aeronautics and astronautics and engineering systems, Dean Hastings has taught courses and seminars in plasma physics, rocket propulsion, advanced space power and propulsion systems, aerospace policy, technology and policy, and space systems engineering. Dean Hastings served as chief scientist to the U.S. Air Force from 1997 to 1999. In that role, he acted as chief scientific adviser to the chief of staff and the secretary and provided assessments on a wide range of scientific and technical issues affecting the Air Force mission. He led several influential studies advising the Air Force investment in space, global energy projection, and options for a science and technology workforce for the 21st century. His recent research has concentrated on issues of space systems and space policy and also on issues related to spacecraft environmental interactions, space propulsion, and space systems engineering. He has published many papers and a book in the field of spacecraft-environment interactions and several papers in space propulsion and space systems. He has also led several national studies on government investment in space technology. Dean Hastings is a fellow of the American Institute of Aeronautics and Astronautics, a fellow of the International Council on Systems Engineering, and a member of the International Academy of Astronautics. He served as a member of the National Science Board and the Applied Physics Lab Science and Technology Advisory Panel, as well as the chair of the Air Force Scientific Advisory Board. He is a member of the MIT Lincoln Laboratory Advisory Committee, a member of the Corporation of Draper Laboratory, and a member of the Intelligence Science Board. He has served on several national committees on issues in the national security space. As dean for undergraduate education, Dean Hastings has broad responsibility for policy and direction in undergraduate education at MIT. He also oversees several administrative offices at MIT including the Office of Undergraduate Advising and Academic Programming, Admissions Office, Global Education and Career Development Center, Office of Experiential Learning, Office of Educational Innovation and Technology, Office of Faculty Support, Office of Minority Education, Registrar's Office, Student Financial Services, the Teaching and Learning Laboratory, and the ROTC Programs. Dean Hastings earned a B.A. in mathematics from Oxford University in England in 1976 and a Ph.D. and an S.M. from MIT in aeronautics and astronautics in 1980 and 1978, respectively.

Thomas R. Howell is an attorney at Dewey & LeBoeuf with more than 25 years of experience practicing in international trade matters. His practice includes litigation pursuant to the U.S. trade remedies (e.g., antidumping, countervailing duty laws, and Section 301 of the Trade Act of 1974), resolution of World Trade Organization disputes, support for international negotiations, and securing market access abroad. A particular area of his experience has been developing and analyzing comprehensive information about industrial policies, private commercial practices, and economic systems outside the United States. Mr. Howell has performed numerous analytic studies for clients on subjects such as foreign high-technology research and development programs and other industrial promotion efforts; national and international cartels, government subsidies, market conditions, and anticompetitive practices in specific sectors in many countries in Europe and Asia; and the formation of trade policy and the functioning of trade regimes. In 2004, he served on the Defense Science Board Task Force on Secure Microchip Supply. In 1985-1986, Mr. Howell represented the U.S. Semiconductor Industry Association in the Section 301 action against Japan, culminating in the opening of the Japanese market to U.S.-made semiconductors. He has since participated in several other market access efforts with respect to Japan in areas such as soda ash, insurance, and telecommunications equipment. Mr. Howell is the author of more than 25 publications on industrial and trade policies of foreign nations. He holds an A.B. from Harvard University and a J.D. from Boston University.

Donald H. Levy *(NAS),* Albert A. Michelson distinguished service professor in chemistry, is the University of Chicago's vice president for research and for national laboratories; CEO of UChicago Argonne, LLC; vice-chairman of the Board of Governors for Argonne; and a member of the Board of Directors for Fermilab. Named to the university position in 2007, Dr. Levy's responsibilities include oversight of the management contracts for both Argonne National Laboratory and Fermi National Accelerator Laboratory, the Office of Technology and Intellectual Policy, the Office of University Research Administration, University-Argonne Research Centers, and all issues related to human subjects research. In addition to his responsibilities for research across the university and Argonne campuses, Levy chairs the Science Policy Council, a collaboration with Argonne, Northwestern University, and the University of Illinois, established in 2005 to enhance Argonne's scientific capabilities, to strengthen the state's technological base and workforce preparation, and to improve Illinois' ability to compete for federal research funding. Dr. Levy joined the University of Chicago faculty in 1967. He is a member of the National Academy of Sciences and a fellow of the American Academy of Arts and Sciences, the American Physical Society, and the American Association for the Advancement of Science. He is a former chairman of the Chemistry Department and he played an important leadership role in planning the new Gordon Center for Integrative Science. A physical chemist, Dr. Levy was a leader in developing and using supersonic jet cooling to study the structure of molecules. Dr. Levy was editor of the *Journal of Chemical Physics* from 1998-2008. His awards include the E. Bright Wilson Award in Spectroscopy and the Ellis Lippincott Award from the Optical Society of America. He holds a Ph.D. in chemistry from the University of California, Berkeley.

Frances S. Ligler *(NAE)* is the Navy's senior scientist for biosensors and biomaterials and current chair of the bioengineering section of the National Academy of Engineering. A researcher in the fields of biosensors and microfluidics, she has also worked in biochemistry, immunology, and proteomics. Dr. Ligler has more than 300 full-length publications and patents, which have been cited more than 6,100 times. She is an elected fellow of the Society for Photooptical Instrumentation Engineering and serves as an associate editor of *Analytical Chemistry* and a regional editor for the Americas for *Biosensors & Bioelectronics*. Her awards include the Navy Superior Civilian Service Medal, the National Drug Control Policy Technology Transfer Award, the Chemical Society Hillebrand Award, Navy Merit Award, NRL Technology Transfer Award, three NRL Edison Awards for Patent of the Year, and the national Women in Science and Engineering (WISE) Outstanding Achievement in Science Award. Additionally, in 2003 she was awarded the Homeland Security Award (Biological, Radiological, Nuclear Field) by the Christopher Columbus Foundation and the Presidential Rank of Distinguished Senior Professional by President Bush. She has previously served on the National Research Council panel on Test and Evaluation of Biological Standoff Detection Systems (2007-2008). She earned a B.S. from Furman University and both a D.Phil. and a D.Sc. from Oxford University.

Heather J. MacLean is a nuclear engineer at the Idaho National Laboratory in the Nuclear Fuels & Materials Division. She is a principal investigator for irradiation tests of advanced nuclear fuels in support of the Fuel Cycle Research and Development Program. Dr. MacLean is responsible for determining fuel compositions, irradiation test parameters, insertion of fuel and material tests into the Advanced Test Reactor, and post-irradiation examination procedures. Dr. MacLean was a senior member of the technical staff at Sandia National Laboratories from 2004 to 2006. She was a member of the Advanced Fuel Cycle Initiative Integration Team, responsible for technical integration activities related to fuels development for advanced thermal- and fast-spectrum systems, and the deputy project manager for the RTG Launch Safety Analysis project for space nuclear power sources. Dr. MacLean's thesis research focused on silver transport in silicon carbide in TRISO-coated fuel particles for high-temperature gas reactors. While a graduate student, Dr. MacLean was a Department of Energy nuclear energy fellowship recipient and conducted research at the Knolls Atomic Power Laboratory in Schenectady, New York. She designed and developed novel graphite/silicon carbide spherical diffusion couples to study thermally accelerated silver migration in silicon carbide. Her experience also include three summers at the Palisades Nuclear Plant in Covert, Michigan, where she analyzed the balance of plant data, provided engineering support during a refueling outage, and analyzed dry fuel storage system performance. Dr. MacLean has been a member of the American Nuclear Society since 1994. She is currently treasurer of the Materials Science & Technology Division and an executive committee member of the Aerospace Nuclear Science & Technology Division. Dr. MacLean earned a B.S. in nuclear engineering from the University of Wisconsin-Madison in 1996 and a Ph.D. in nuclear engineering at the Massachusetts Institute of Technology in 2004.

Fawwaz T. Ulaby *(NAE)* is the Arthur Thurnau Professor of Electrical Engineering and Computer Science at the University of Michigan. He was previously the founding provost and executive vice president for academic affairs of the King Abdullah University of Science and Technology (KAUST), a graduate research university under development along the Red Sea in Saudi Arabia. Prior to assuming this position, Dr. Ulaby was the R. Jamison and Betty Williams Professor of Electrical Engineering and Computer Science at the University of Michigan, where he had also served as vice president for research (1999-2005). He is a member of the National Academy of Engineering and a fellow of IEEE and the American Association for the Advancement of Science, and he serves on several scientific boards and commissions. Since joining the University of Michigan faculty in 1984, Dr. Ulaby has directed numerous interdisciplinary, NASA-funded projects aimed at the development of high-resolution satellite radar sensors for mapping Earth's terrestrial environment. He also served as the founding director of a NASA-funded Center for Space Terahertz Technology, whose research was aimed at the development of microelectronic devices and circuits that operate at wavelengths intermediate between the infrared and the microwave regions of the electromagnetic spectrum. Over his academic career, he has supervised 115 highly motivated and talented graduate students. Dr. Ulaby received his Ph.D. in electrical engineering from the University of Texas at Austin in 1968.

Kathleen A. Walsh is an assistant professor of national security affairs in the National Security Decision Making Department at the Naval War College (NWC), where she teaches policymaking and process (PMP) and the contemporary staff environment (CSE). Her research focuses on China and the Asia-Pacific region, particularly security and technology issues. Her current research projects include assessing national security implications of China's commercial shipbuilding enterprise and, as a separate project, implications from China's increasing role in UN peacekeeping operations. She is author of numerous publications, including "The Role, Promise and Challenges of Dual-Use Technologies in National Defense," chapter 7 in *The Modern Defense Industry: Political, Economic and Technological Issues* (Richard A. Bitzinger, ed., Praeger, 2009); "National Security Challenges and Competition: Defense and Space R&D in the Chinese Strategic Context," *Technology in Society* (July 2008); *Post-Conflict Borders and UN Peace Operations: Part 1: Border Security, Trade Controls, and UN Peace Operations* (Henry L. Stimson Center, 2007); and *Foreign High-Tech R&D in China: Risks, Rewards, and Implications for US-China Relations* (Stimson Center, 2003), as well as numerous congressional testimonies, public presentations, and high-level government briefings. Prior to joining the NWC, Dr. Walsh was a senior consultant to several Washington-area think tanks (e.g., CSIS, Monterey Institute, and Stimson Center) and a senior associate at the Stimson Center as well as at a defense consulting firm. She was appointed in 2007 as a member of the National Research Council's Committee on Assessing the Need for a National Defense Stockpile and as a member of the Office of Director of National Intelligence's Summer Hard Problem (SHARP) Program. She is an affiliate of the China Maritime Studies Institute (CMSI), participates in the Asia Pacific Study Group, and is a member of the U.S. Council on Security Cooperation in the Asia Pacific (CSCAP) and its Study Group on the Implications for Naval Enhancement in the Asia Pacific (2009-2010).

Heather Wilson represented New Mexico in the U.S. Congress from 1998-2009. The Hon. Wilson served on the Energy and Commerce Committee for the duration of her tenure in Congress, where she was involved in all matters relating to the oversight of the Department of Energy, the Nuclear Regulatory Commission, and the Environmental Protection Agency, including matters related to the Clean Water Act and Superfund laws, as well as oversight of operations and security at our National Laboratories. During her 10 years in the House, the Hon. Wilson was a prominent leader on a broad range of national security issues. For six years she chaired the House Republican Policy Committee on National Security and Homeland Security and produced two major policy studies on non-proliferation and nuclear deterrence policy. Before entering public service, the Hon. Wilson was president of Keystone International, Inc., a company that performed business development and program planning work in the United States and the former Soviet Union. Prior to that, the Hon. Wilson was the director for defense policy and arms control on the National Security Council Staff at the White House. There, she oversaw development of U.S. policy and negotiating strategy that led to the completion of the Conventional Forces in Europe Treaty and chaired the inter-agency group that developed guidance for the American delegation in Vienna, Austria. From 1987 to 1989, the Hon. Wilson was an Air Force Officer assigned to the U.S. mission to NATO in Brussels, Belgium. During the spring of 1989, the Hon. Wilson was the acting representative of the Secretary of Defense in the U.S. Delegation to the Conventional Forces in Europe negotiations in Vienna, Austria. She was also the U.S. mission's expert on British, Spanish, and Portuguese defense plans. From 1985 to 1987, the Hon. Wilson served at the headquarters of the U.S. Air Force in the United Kingdom, where she served as the principal contact for the British Government on matters related to planning and negotiating the beddown of nuclear capable cruise missiles at RAF Molesworth and RAF Greenham Common. The Hon. Wilson is a distinguished graduate of the U.S. Air Force Academy in 1982, and, as a Rhodes Scholar, she earned her master's and doctoral degrees from Oxford University in England. Her doctoral thesis, published as a book, earned a major prize from the International Committee of the Red Cross in Geneva, Switzerland, for a major contribution to the study of international humanitarian law. She was the first American ever to have received this award.

Appendix B

Meetings and Speakers

MEETING 1

November 17-18, 2009
National Academy of Sciences Building
Washington, D.C.

The Decline and Fall of American Science Leadership
Duane R. Shelton, World Technology Evaluation Center

The National Security Imperative for Global S&T Engagement
Gerald Epstein, Center for Science, Technology & Security Policy

Presentation on Russia and Kazakhstan
Glenn Schweitzer, Office for Central Europe and Eurasia

The Implications of Strategies on Technological Innovation in China for Global Economic and Environmental Security
Fred Steward, Brunel University

MEETING 2

December 7-8, 2009
National Academy of Sciences Building
Washington, D.C.

Innovation and Development Strategies of China and India and the Changing Global Environment: Implications for the US
Carl Dahlman, Georgetown University

Global Innovation Strategies, The Role of Public-Private-Partnerships
Charles Wessner, Board on Science, Technology, and Economic Policy, National Research Council

Brazilian University Research: Presentation to the Committee on Global Science and Technology Strategies and Their Effect on U.S. National Security, of the U. S. National Academies
Silvio Salinas, Institute of Physics, University of São Paulo, Brazil

The Changing Face of R&D, Singapore
Peter Schwartz, Global Business Network

Science and Technology Policy in Japan
Takashi Inutsuka, Embassy of Japan

The Unrequited U.S.-Japan National Security Science & Technology Relationship
Paul Giarra, Global Strategies and Transformation
Jim Delaney, Institute for Defense Analysis

US-Japan Research, Development and Acquisition Cooperation with Department of Defense and US Industry
Frank Cevasco, Cevasco International

An Objective, Reliable and Accurate Measure of Research Leadership
Richard Klavans, SciTech Strategies, Inc.
Kevin Boyack, SciTech Strategies, Inc.

China's National Innovation System and R&D Strategies
Somi Seong, RAND Corporation

Science &Technology Policies and Practices in India, China, and Brazil: The Case of Biotechnology and Life Sciences
Peter Singer, McLauglin-Rotman Centre for Global Health, University of Toronto
Rahim Rezaie, University of Toronto

MEETING 3

January 20-21, 2010
National Academy of Sciences Building
Washington, D.C.

The Science of Science & Innovation Policy
Julia Lane, National Science Foundation

Global R&D Innovation from an Indian Perspective
Y. S. Rajan, Confederation of Indian Industry

Evolution of the Science, Technology and Innovation Concepts in Brazil: From Discourse to Relevance
Hernan Chaimovich, The Brazilian Academy of Sciences

Current Developments in Russian Science & Technology: Between Ambitions and Realities
Peter Radoev Zashev, Emerging Markets Research University Research Group, International Business and Culture, Kymenlaakso University of Applied Sciences, Finland

Brazil Science, Technology and Innovation Plan for National Development Action Plan 2007-2010
Flavio Grynszpan, Motorola Brazil

Science and Engineering Research Council, Powering Innovations Empowering Lives
Charles Zukoski, Science and Engineering Research Council, Agency for Science Technology and Research, Singapore, University of Illinois at Urbana-Champaign

China's Emerging Technological Trajectory Critical Issues and Implications
Denis Fred Simon, The Pennsylvania State University

The Brazilian Innovation System Figures and Problems
Carlos Pacheco, State University of Campinas – UNICAMP

Overview of Science, Technology & Innovation Systems in Brazil
Eduardo M. Krieger, Harvard Medical School, Hypertension Unit, Heart Institute, Brazil

Russia's Dilemma: Natural Resource State or High-Tech Player?
Loren Graham, Program in Science, Technology, and Society, Massachusetts Institute of Technology

MEETING 4

March 8-9, 2010
Beckman Center of the National Academies
Irvine, California

Writing Meeting