Managing Materials for a Twenty-first Century Military

Committee on Assessing the Need for a Defense Stockpile

National Materials Advisory Board

Division on Engineering and Physical Sciences

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Cover: A titanium splash. Titanium is a light, strong, lustrous, corrosion-resistant metal that can withstand extreme temperatures. Titanium alloys have many uses in military systems, including in aircraft, armor plating, naval ships, spacecraft, and missiles. SOURCE: Gerald Petrak, Wright-Patterson Air Force Base.

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Preface

In the report language for the 2006 National Defense Authorization Act, the Armed Services Committee of the U.S. House of Representatives (HASC) directed the Department of Defense (DoD) (1) to review its policy for disposing of material in the National Defense Stockpile (NDS) and (2) to determine whether the NDS should be reconfigured "to adapt to current world market conditions to ensure future availability of materials required for defense needs."[1] In July 2006, in response to this request, DoD, through the Defense National Stockpile Center (DNSC) at the Defense Logistics Agency, issued a report suggesting that the National Research Council (NRC) be asked to carry out a study on the NDS.[2] In response, the NRC formed the Committee on Assessing the Need for a Defense Stockpile to assess the continuing need for and value of the NDS and, if needed, to develop general principles for its operation and configuration. In carrying out this charge the committee was asked to

1. Describe, drawing on previous studies of the National Academies, current national defense materials needs, taking account of the recent evolution of the domestic and global materials supply chains and the impact of growing international materials needs on materials availability.

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[1]Armed Services Committee of the U.S. House of Representatives, Report of the Committee on Armed Services, House of Representatives, on H.R. 1815 together with additional and dissenting views. Report 109-89, p. 477. Washington, D.C. (2005).

[2]U.S. Department of Defense, Report in Response to House Armed Services Committee Request on p. 477 of Report 109-89, Washington, D.C. (2006).

2. Re-assess the national need for the stockpiling and safe, secure, and environmentally sound stewardship for strategic and critical defense-related materials in the United States. In conducting this assessment the committee will consider other nations' stockpiling initiatives.
3. Recommend general concepts and scenarios for the operation of any future national stockpile that would consider the roles of government, industry, and the wider materials community in the identification of specific defense materials needs.

By NRC standards, the time available to the committee to do its work (fewer than 6 months elapsed between the committee's first meeting and this report going into NRC review) was much shorter than usual. As a result, the scope of the committee's work had to be limited to what was achievable in a comprehensive way within the expedited schedule. The committee was not able to analyze in depth specific defense materials needs, but this report does provide an outline of those needs based on the work of other committees and studies, including NRC reports (as called for in the charge), the expertise of the committee members, presentations to the committee, and information gathered by committee members during the study. While the committee began its work by considering the narrow matter of need for the stockpile, its focus evolved over the course of the study to considering the larger matter of assuring supply. Also, while the committee drew conclusions on stockpiling as one method to assure supply—the core issue in the committee's opinion—it did not have the time or resources to assess the safety, security, or environmentally sound stewardship of materials in the stockpile. These stewardship issues could be considered in any future work on the configuration of the stockpile. The committee, in fact, hopes that this study will only be a beginning and that serious consideration will be given to a more thorough, deliberate, and longer look into the important issues that remain.

The NRC populated the committee with members having a broad range of backgrounds and interests.[3] They came from government laboratories, large and small companies, and academia. While several members had some experience or knowledge of stockpile history and operations, the subject was a new one for a majority of the members. This was by design, and the committee embarked on the study with no preconceived ideas about the outcome.

The committee heard from representatives of DoD, the U.S. Geological Survey, the Institute for Defense Analyses, the Department of Commerce, academic institutions, industry associations, and aerospace industries. It reviewed stockpile legislation, DoD policies, past studies by the General Accounting Office, the Congressional Budget Office, and the NRC, and other reports on national defense materials needs. The full committee met twice in open session and several times by teleconference.

[3]Note that members of this committee served in a personal capacity and the views they express in this report do not reflect those of their employers or any other institution with which they are affiliated.

Additionally, several members tasked with major report drafting responsibilities met twice in Washington, D.C. In both cases, the drafts were vetted by the committee as a whole. The committee then met a third and final time in plenary closed session to come to consensus on this report and its conclusions and recommendations.

While the study was under way, the NRC's Board on Earth Sciences and Resources was in the midst of a related study, on minerals and mineral products critical to industry and emerging technologies in the U.S. economy. While neither committee was privy to the other's private deliberations in closed committee sessions or draft reports, the committees did share the publicly available information they had gathered. This committee is grateful to the members and staff of the Committee on Critical Mineral Impacts on the U.S. Economy for their cooperation.

My thanks go to the committee for its extraordinary efforts to produce this report in a short time. Although members came together from a variety of professional backgrounds, the committee was united in its diligence and dedication to completing its task—a task all quickly saw as being important to the country. Overall, this was an enjoyable and educational experience. None of it would have been possible without the commitment of the NRC staff, who supported the committee's work and made it possible for the committee to adhere to its expedited schedule.

The committee worked diligently to understand the legislation, policies, and actual operation of the NDS as well as legislation and policy governing other aspects of materials supply, logistics, and the defense industrial base. Significant effort was devoted to analyzing the history of stockpile operations as they relate to defense planning. In the end, the committee was struck by the fact that despite the efforts of interested organizations and dedicated individuals in DoD and the Congress to make critical and strategic materials decisions based on sound analysis and assessment of risk, the NDS remains a low-priority activity for DoD leadership.

The committee has attempted to call attention to the dramatically different situation in which the country finds itself compared with 70 years ago, when much of the stockpile legislation and policy was originally conceived. The globalization of materials production and supply has radically changed the ability of the United States to produce and to procure materials vital to defense needs. Yet, little has been done in the face of changed materials needs in the military nor have the methods of computing stockpile requirements or the means of assuring continued supplies been adapted to reflect these changes. The committee is hopeful that this report will be the catalyst for long-awaited and much-needed action.

Robert Latiff
Chair

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 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:

Jack E. Buffington, University of Arkansas,
John Busch, IBIS Associates,
Dianne Chong, The Boeing Company,
Fiona Doyle, University of California, Berkeley,
Steven W. Freiman, National Institute of Standards and Technology (retired),
Ivan L. Herring, General Motors (retired),
John D. Morgan, U.S. Bureau of Mines (retired), and
Subhash C. Singhal, Pacific Northwest National Laboratory.

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 Elisabeth M. Drake, Massachusetts Institute

of Technology. Appointed by the National Research Council, 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

Summary

It is a different world from when the National Defense Stockpile (NDS) was established just before World War II. The nature of the global economy has changed, not only expanding U.S. access to the international market but also increasing competition from a growing list of other countries seeking access to sometimes scarce raw materials. In the twenty-first century, the United States is faced with several asymmetric national security threats that span the globe, requiring the military to be able to respond rapidly to sudden increased demands. Defense needs are now defined in a new context that is focused on capabilities-based planning rather than on threat-based planning. At the same time, the supply of defense systems has been transformed from a government-dominated military-industrial complex to a global, dual-use, civil-military industrial complex. The U.S. military is now more dependent on civilian industry than it was 70 years ago, when the NDS was established. Civilian industry, in turn, depends increasingly on global sourcing and on overseas R&D programs and other foreign assets. Meanwhile, industrial practice of inventory control has shifted from stockpiling and holding reserves to a just-in-time, or sense-and-respond, system for managing supply chains.

In this context, the Committee on Assessing the Need for a Defense Stockpile of the National Research Council (NRC) was asked to assess the continuing need for and value of the NDS. It was also asked to discuss current defense materials needs, to reassess the necessity of stockpiling of strategic and critical defense-related materials and, if called for, to develop some general principles for any future operation and configuration.

In response to this charge, the committee reviewed previous government-sponsored studies as well as legislation pertaining to the stockpile. It analyzed the outputs of years' worth of work by the Defense National Stockpile Center and reviewed the methodologies used to develop stockpile materials requirements. Its report discusses current defense materials needs, the changes in ways of generating defense requirements and system requirements, and the dramatic changes in the global supply and availability of materials. Other policies relating to defense industrial base needs are considered, as well as other tools available to assure a continuing supply of materials.

The committee concluded based on the preponderance of evidence it considered that the operation of the current NDS is disconnected from actual national defense materials needs in the twenty-first century and from national defense strategies and operational priorities. While there have been frequent changes in law and policy governing military planning and operations, there have not been any concomitant changes in the design or operation of the NDS.

Conclusion 1: The design, structure, and operation of the National Defense Stockpile render it ineffective in responding to modern needs and threats.

In the committee's judgment, there remain three major threats to assuring the supply of materials critical to the national defense:

- Increased demand from around the world for mineral commodities and materials.
- Diminished domestic supply and processing capability along with greater dependence on foreign sources.
- Higher risk of and uncertainty about supply disruptions owing to the fragmentation of global supply chains.

Modern minerals supply chains to U.S. industry and indeed to global industry are characterized by outsourcing and offshoring. Reductions over time in U.S. mining operations, processing facilities, and metal fabrication operations have limited U.S. capacity for mining or processing ore, and in some cases the country is entirely reliant on foreign sources in some key minerals sectors. Much of the current content of the U.S. defense materials stockpile reflects history rather than current national security needs, and the process to assess stockpile requirements and goals does not identify specific materials needed to produce current or planned military systems and platforms. Consequently, there may be a demand for specific, high-priority, defense-related materials that is not being addressed because too little is known about materials usage.

Conclusion 2: The Department of Defense appears not to fully understand its needs for specific materials or to have adequate information on their supply.

Although in principle inventories of defense materials could be valuable in the current and future strategic and economic environment, the existing stockpile system is not properly designed to meet national defense materials. The system and its operation are neither timely nor based on up-to-date information. The process is episodic rather than dynamic, and the lack of data on demands for specific materials means the NDS cannot be responsive to changes in world markets in real time. There does not appear to be a strong relationship between stockpile policy and national security objectives nor is there an understanding of global supply chain management practice. The committee reports that many of the earlier conclusions and recommendations coming from one forum or another are similar to each other and to those coming from this committee. However, they were for the most part never acted on or implemented, leading the committee to the conclusion that the operation and future of the NDS have never been high on the agenda of the DoD leadership, nor do they seem to be now.

A system to ensure against disruptions to the supply of materials of defense interest would benefit from a well-defined and dynamic model that allows identification of critical materials. There remains an urgent need to improve the collection of information, both here and abroad, on the availability of these materials, without which there is no way to rationalize and motivate government intervention in the supply of these critical materials.

Conclusion 3: A lack of good data and information from either domestic or offshore sources on the availability of materials impedes the effective management of defense-critical supply chains.

In the committee's judgment, dependence on supplies from abroad is not per se a cause for concern. But it may become so when combined with other factors such as concentration of supply, political instability in the source regions, and greater competition for mineral resources across the globe. Twenty-first century threats to national security are different from those associated with the more familiar concepts of war and conflict of the last century. In the committee's judgment, and notwithstanding the ineffectiveness of the current configuration of the NDS, there remains a role for the federal government in the active management of the supply of materials for defense systems.

Conclusion 4: Owing to changes in the global threat environment and changes in the U.S. industrial base, the emergence of new demands on materials supplies, the ineffectiveness of the National Defense Stockpile, and the resultant potential for new disruptions to the supply chains for defense-critical materials, the committee believes there is a need for a new approach in the form of a national defense-materials management system.

The framework for a materials management system needs to reflect current geopolitics and take into account that U.S. defense and commercial supply chains are mutually dependent on one another and on global economic dynamics. Having considered which tools, in addition to or instead of a stockpile, could help to assure a continuing supply of materials, the committee concludes that a whole new approach is required. It found that the private sector—focused as it is on agility and efficiency and having been directly impacted by global materials' availability—has embraced the concepts of supply-chain management. Where private sector stockpiles of industrial materials or parts are deemed absolutely necessary, they are resorted to, but only sparingly.

Identifying the materials needs of the twenty-first century military, understanding the risk of disruptions in the supply chains for those materials, and planning actions to mitigate the impact of surges in requirements and unexpected shortfalls in inputs demands a systematic and coordinated policy response.

Recommendation 1: To meet the national strategic objective of assuring the timely availability of materials necessary to maintain the national defense capabilities of the United States into the foreseeable future, the Secretary of Defense should establish a new system for managing the supply of these materials.

The committee is recommending not just a new organizational construct or a bureaucratic answer but a totally new system approach, including appropriate policy, regulatory, and legislative changes. The new system would be based on a coordinated strategy designed to ensure the availability of critical materials to meet a well-defined and dynamic model of defense needs. Holding a materials inventory would be one of the many tools available to a defense-materials management system. More important, however, a new system would (1) assess the risks in order to make better-informed decisions on mitigating them (for example, deciding if stocks need to be held); (2) spot vulnerabilities in the supply chain and redesign it to eliminate or mitigate them before events occur; and (3) design and manage the supply chain to be more resilient to disruption. The new system will depend critically on the conduct of analyses that identify defense-specific materials needs.

Notwithstanding any future decisions by the Secretary of Defense on how to implement a new system, the committee provides some general operational principles.

Recommendation 2: The operation of a system for managing the materials needed for national defense should be guided by the following general principles:

- **Establish an ongoing analytical process to identify materials that are critical to defense systems. The analysis should include gathering information on short-term and long-term needs for primary and secondary (component) materials. The process could include a system of annual reporting from the services and defense agencies, starting at the procurement level, which identifies strategic and critical materials and the potential vulnerabilities in their supply.**
- **Integrate the ongoing operation of the new system with current defense planning.**
- **Set a flexible policy framework that is integrated with the full set of legislation and policies governing the procurement of defense-related systems from U.S. contractors.**
- **Use all available tools to support and stabilize robust supply chains in the increasingly changeable and global environment for materials supply, including the holding of a materials inventory that would serve as a flexible, continuously changing buffer stock with constant and timely management for restocking and balance.**
- **Provide the option of partnering with private industry as well as options for outsourcing and offshoring.**
- **Provide an appropriate and robust information system and forecasting tools.**
- **Solicit advisory input from industry, academia, and other stakeholders, as appropriate, accompanied by communicating with stakeholders and the public on the general status and activities of the materials management system.**
- **Evaluate recycling and substitution as additional sources of key materials.**
- **Perform risk assessments that take into account present and future environmental constraints on some defense material availabilities.**

As discussed earlier, no matter what the future holds for the supply of defense-critical materials, there is an urgent need to improve the collection of information—from both domestic and offshore sources—on the availability of materials for defense needs.

Recommendation 3: The federal government should improve and secure the systems for gathering data and information—both at home and abroad—on the availability of materials for defense needs. It must be able to obtain accurate data on

- **The geographic locations of secure supplies of critical materials and of alternative supplies;**
- **The potential for market and geopolitical disruptions as well as logistical and transportation upsets and the risks posed by them; and**
- **The use of materials in defense applications, in the nondefense industrial sectors of the United States, and in the rest of the world's large commodity-consuming nations.**

1

Overview: Observations, Conclusions, and Recommendations

Since ancient times, governments and private firms have kept stockpiles of essential goods such as foodstuffs, materials essential for industry, drugs in case of epidemics, and military supplies in case of conflicts. Since 1939 the U.S. government has been stockpiling "critical strategic materials for national defense purposes."[1] Operated by the Defense National Stockpile Center (DNSC), a field activity of the Defense Logistics Agency, as of May 2007 the National Defense Stockpile (NDS) stored 21 materials at locations throughout the United States (Box 1-1). Examples of commodities are platinum, used for chemical catalyst applications, including catalytic converters to treat automotive emissions, and for many other purposes; germanium, used for detectors, fiber-optic systems, and infrared optics; and ferrochrome, a metal additive used in stainless steel and other specialized alloys. The NDS is mandated by law to hold strategic and critical materials in the interest of national defense to preclude a "dangerous and costly dependence" on foreign sources of supply in times of national emergency.[2] However, the purpose of the NDS is not just military; rather, it is mandated by law to hold materials for all essential civilian and military uses in times of emergency.[3]

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[1]Operating under the authority of the Strategic and Critical Stock Piling Act (50 U.S.C. 98a et seq.), the stockpile was created shortly before World War II (June 7, 1939).

[2]Chapter 6 of this report gives details of the materials requirements reporting process and criteria used to determine which strategic and critical materials should be held by the stockpile.

[3]As discussed later in the report, today the stockpile's allowed use does not extend to releasing materials solely for economic purposes, such as to control prices in peacetime.

BOX 1-1
Materials Being Held by the National Defense Stockpile (May 2007)

At the time of writing, the NDS stored 21 materials. Two were being held against a national emergency: quartz crystal and beryllium metal hot pressed powder (HPP). The NDS had 171 short tons (ST) of beryllium HPP in inventory of which 121 ST had been authorized for sale but which were being held pending a determination of whether the HPP should continue to be held for DoD needs or Department of Energy needs.

Twenty-five commodities are available for sale:

- Aluminum oxide
- Beryllium-copper master alloy
- Beryllium, vacuum cast
- Chromium metal
- Cobalt
- Columbium metal ingots
- Diamond stones
- Ferrochromium, high carbon
- Ferrochromium, low carbon
- Germanium
- Iodine
- Iridium
- Manganese ferro, high carbon
- Manganese ore, metallurgical grade
- Manganese ore, battery grade
- Mica
- Platinum
- Talc, block/lump
- Talc, ground
- Tantalum carbide powder
- Tin
- Tungsten metal powder
- Tungsten ores and concentrates
- Vegetable tannin
- Zinc

The NDS also stores mercury, which is not for sale and is expected to be shipped to the Hawthorne Army Depot in Nevada during 2007.

At the time of writing, DNSC operates 17 active storage sites having material available for sale or sold and awaiting shipment, with 8 additional sites awaiting environmental restoration or certification before being turned over to the property owner. By the end of FY2007, only three staffed sites will be operating.

Beginning in 1992, the U.S. Congress directed DNSC to sell the bulk of the commodities in the stockpile. Since 1993, DNSC sales have totaled approximately $6.6 billion. Over the same period, the world economy has become increasingly global as have the supply chains that feed the industries supplying the national defense system and the essential civilian industries that the stockpile was meant to protect. Against this background, the geopolitical situation has changed radically not only since World War II but also more recently with the emergence of new economic powers such as China and India, the demise of the Soviet Union and the emergence of a new Russia, and the rise of international terrorism as a sustained threat to the national security of the United States.

With all these changes a question arises: Should the United States continue to maintain a stockpile of critical materials and, if it should, what might be the general principles for its operation and configuration? With the changing nature of U.S. manufacturing against a backdrop of increasingly global and fragmented supply chains for materials, products, and systems and the trend in the defense establishment's acquisition of systems, subsystems, and components increasingly from foreign suppliers, assessing the future need for a national stockpile only becomes more complex. In addition, the materials needed for the nation's security and defense are considerably different from those needed 70 years ago, when the stockpile was established. It is for these reasons that this study has been undertaken.

This report examines the history of the stockpile so as to understand the rationale for its operation over the last seven decades. It considers how the world has changed in the same time frame and how military planning and the global sourcing of materials for defense systems have evolved. It looks at the way the Department of Defense (DoD) currently forecasts the materials the stockpile needs to hold. Finally, the report draws some conclusions about the need for a mechanism that assures the supply of materials critical to U.S. defense systems. This chapter serves as an overview of the main observations and findings of the committee during the course of this study and presents the committee's conclusions and recommendations. The chapters that follow present the data gathered and the committee's findings in more detail. In some instances appendixes provide greater detail.

GENESIS OF THIS STUDY

A report by the Committee on Armed Services of the U.S. House of Representatives (HASC) on the FY2006 National Defense Authorization Act noted that over 95 percent of the materials in the NDS at that time had been determined to be in excess of DoD needs and was being sold off.[4] The HASC report also noted the then-current market conditions, particularly with respect to titanium, and the increasing reliance on foreign sources of supply for defense programs. In response, HASC expressed its concerns about DoD's ability to ensure the timely availability of materials to meet the current needs of the military services. It directed the Secretary of Defense to "review the DoD's current policy to dispose of material and determine whether the NDS should be re-configured to adapt to current world market conditions to ensure future availability of materials required for defense needs."

The DoD report submitted to the Congress in response to this request noted that material shortages arise for a variety of reasons, not just cyclical surges in supply or demand (DoD, 2006). It concluded that while a stockpile was a valid option when shortfalls for critical applications could not be resolved using other tools, it was not clear that a reconfiguration of the stockpile would be of "net benefit to the

[4]For the text of the report, see http://frwebgate.access.gpo.gov/cgi-bin/useftp.cgi?IPaddress=162.140.64.21&filename=hr089.pdf&directory=/diskb/wais/data/109_cong_reports. Accessed June 2007.

nation" or what the appropriate format should be. The report noted that information was lacking on topics such as materials forecasted to be required for future weapons systems and other defense production; domestic production capacity for critical materials; and alternative suggestions for addressing particular shortages. It suggested that further research was needed to understand better the following:

- Materials shortages and resulting consequences.
- Impacts on the delivery of end items for critical defense systems.
- Use of nonstockpile tools to mitigate problems and the limitations of such use.
- For the stockpile option, how it should be configured, including the form and quantities of materials to be stockpiled and the conditions under which materials would be released (and to whom) or replenished.
- A comparison of stockpile and nonstockpile solutions, including relative costs and effectiveness.
- What new legal authority would be required to reconfigure the stockpile?

The DoD report recommended the NRC be asked to undertake a study on the future of the NDS and to recommend a path forward.

OBSERVATIONS

The committee approach to this study was to review the NDS as currently configured, to assess its value and whether or not it is effective, and to develop some general principles for any future operation and configuration. In conducting its work, the committee reviewed previous government-sponsored studies as well as the legislation pertaining to the stockpile. It analyzed the output of years of work by the DNSC, reviewed the methodologies used to develop stockpile materials requirements, and compared the results of those studies with data on actual sales and purchases. The committee investigated current defense materials needs, the changes in defense requirements and system requirements, and the dramatic global changes in materials supply. Other policies relating to defense industrial base needs were considered, as well as other tools available to assure a continuing supply of materials. Based on the information gathered during the course of this study and based on its collective expertise, the committee has developed a set of observations and conclusions about the configuration of and continued viability of the National Defense Stockpile.

The committee wishes to note that this study was conducted on a very compressed schedule—with less than 6 months between the first committee meeting and the report entering NRC review. In this regard the committee stresses that a detailed analysis of specific materials needs—their forms, costs, effectiveness, and so on—would require further and more deliberate study.

Government Inaction on Previous Study Recommendations

While this report places the question of the NDS in a more current context and addresses some new topics, the committee was struck as it read previous reports that much of what it debated and indeed many of its conclusions are remarkably similar to the outcomes of many earlier studies by various entities. A selection of these reports is summarized in Chapter 2, which also looks at the history of the NDS. Some of the more pertinent conclusions and recommendations from those reports are summarized here.

The final report of the National Commission on Materials Policy (NCMP) (NCMP, 1973) stated that U.S. materials demand on the rest of the world's supply was growing at a time when other nations' demands were growing even faster. The report noted that in the past the United States had had little difficulty importing the minerals necessary to satisfy its demands but that the situation might change, for two reasons: (1) increasing competition for scarce resources and (2) the possibility of actions to restrict supplies and/or increase prices. In 1974 the Government Accounting Office (GAO) issued a report titled *U.S. Actions Needed to Cope with Commodity Shortages* (GAO, 1974). The report noted that shortages of basic commodities had begun to cause serious economic, social, and political problems for the United States and other countries. Another GAO report, *Stockpile Objectives of Strategic and Critical Materials Should Be Reconsidered Because of Shortages* (GAO, 1975), noted that stockpile policy at that time assumed that the United States could import from all countries except communist countries and those involved in a conflict. The GAO opined that this assumption conflicted with the world resources outlook and that long-range planning was necessary due to the increasing demand for resources. The report noted that the United States relied heavily on imports of some of the materials that had been authorized to be sold off and questioned whether enough thought was being given to the nation's future supplies of these materials. If long-range planning for these materials had been in effect earlier, it said, the disposals might never have been authorized.

A 1983 Congressional Budget Office (CBO) report noted that diversifying sources of supply offers both U.S. metal-using industries and the economy as a whole greater assurance that the ill effects of supply contingencies could be contained (CBO, 1983). Diversification, the report said, would provide alternative supplies during a disruption and lessen the chance of a cartel manipulating minerals markets. The CBO report also noted that research and development (R&D) in minerals exploration and production and materials applications could limit U.S. vulnerability to shortages of imported minerals. The CBO suggested that the Congress might wish to consider legislation to promote R&D for minerals and metallurgical science.

While many earlier conclusions and recommendations made in one forum or another are similar to those developed by this committee and reported below, the recommendations outlined above largely were never acted on or implemented. The committee also found striking the fact that much of the writing on this subject was at least a decade old.

The committee concludes that the operation and future of the National Defense Stockpile had never been high on the agenda of the DoD leadership, nor does it seem to be now.

Fundamental Shift in Global Materials Supply and Demand

The global backdrop of materials production and supply against which NDS policies and decisions have always been made has changed in fundamental and dramatic ways. Other nations' economies are growing rapidly, with a concomitant and explosive increase in demand for the same raw materials that are needed by U.S. defense and civilian industries. There has also been a marked increase in the foreign supply of manufactured goods to the U.S. civilian and military sectors. The United States faces serious global competition for materials and, often, significantly higher commodity prices than in recent years. These issues are discussed in Chapter 3, which also notes that the situation is compounded by a much-reduced domestic supply and a seriously diminished materials processing industry. The ability, from the standpoint of both technical know-how and physical infrastructure, of U.S. sources to process raw materials has lessened dramatically. In many cases, raw materials must be shipped offshore for processing into usable form. The committee notes that the United States is heavily reliant on one or two countries for many of its most important materials resources and processing capabilities. This reliance has steadily and rapidly increased in recent years. Thus, the ways in which the U.S. supply of essential materials for national defense is vulnerable to disruptions are different and more varied than in the past and will require different remedies.

Changing World, New Context

In the face of the dramatically changed world and national situations since World War II and the establishment of the NDS, the DoD and the U.S. military have adapted, at times more readily than other countries have, their weapons and strategies. Since the end of the Cold War and even more recently, there has been a revolution in military affairs and a significant transformation in the nation's military forces. These issues are discussed in Chapter 4, where the committee notes that while there have been frequent changes in law and policy governing military planning and operations, concomitant changes have not been made in the design or operation of the NDS.

Stockpile management, discussed in detail in Chapter 6, and defense industrial policy, discussed in Chapter 5, continue to reflect thinking from past eras and appear to remain tied to old constructs. While the demand models and availability estimates used to estimate materials requirements for the stockpile may have been modified, the changes have occurred at the margins. The committee observed that the conceptual framework and modeling are gross estimates that do not capture specific information relevant to twenty-first century military needs.

While high-level studies have been conducted for the DoD concerning future materials needs—one such is *Defense Materials Needs for the 21st Century* (NRC, 2003)—and are summarized in Chapter 4 and discussed in more detail in Appendix C, it is not apparent to the committee that any effort has been made to incorporate the findings of these reports into materials planning processes. Table 4-3 in Chapter 4 shows the uses of selected strategic and critical materials and their import reliance. The information there shows the diversity of materials that are used in both specialized and nonspecialized systems and subsystems. The committee notes that in 1937, when the stockpile was established, the United States only had to be concerned about maintaining a supply of raw materials since it had the technology to both process the raw materials and manufacture any engineered product as long as the raw materials were available. Today, however, it needs to be concerned about whether it has the capacity to produce or obtain sophisticated engineered materials.

The committee observed that the modeling process used to assess stockpile requirements and goals, discussed in Chapter 6, does not generate defense-specific requirements. Further, the materials currently identified as needing to remain in the stockpile were not identified by the modeling process at all: Indeed, they have been identified consistently for more than 15 years through a separate interagency process. The committee questions why DoD continues to execute the very detailed and complicated modeling process if that process does not influence the stockpile requirements or configuration.

Even disregarding changes in how the U.S. government assesses the reliability of worldwide suppliers of materials, there has been little or no recognition of the dramatic change in global supply and demand. Modeling still assumes that disruptions will be only temporary and that short of a physical impediment, the United States will ultimately be able to get what it wants. The committee believes that the current materials supply situation is radically different from what it was 20 years ago and that this difference warrants a serious reevaluation of this assumption. In the past, the United States was heavily dependent on foreign sources but, since it was at the time the leading world consumer, the country could presumably overcome problems of unstable or marginally reliable sources. With the explosive growth in the economies of other nations, most notably China, and the increasing share of world output of critical materials produced in other nations, again notably China, the United States is no longer the main factor in either world supply or demand.

CONCLUSIONS

Paraphrasing the charge for this study, the committee was asked to assess the continuing need for and value of the NDS. It was also asked to discuss current defense materials needs, to reassess the national need for the stockpiling of strategic and critical defense-related materials and, if needed, to develop some general principles for any future operation and configuration. In response the committee offers the following conclusions.

Continuing Need for and Value of the National Defense Stockpile

The NDS as originally conceived was designed to ensure support for large-scale mobilization during a national emergency and for reconstitution thereafter. However, the committee believes that this NDS mission is disconnected from current national defense strategies and operational priorities. Today's pressing task is to support a military in transformation that is conducting expeditionary operations against changing threats around the world without the benefit of national mobilization. The committee is troubled by the inability of the NDS to adapt to this changed context, as manifested by the serious lag between the evolved U.S. defense strategy and any associated updating of the NDS analysis. There is also a disconnect between the transformation of DoD force planning to a capability-based process and the obsolete analytical methods used to specify materials requirements for the NDS.

The committee is concerned that while there have been some attempts over the years to make the assumptions underlying the conflict scenarios used to set materials requirements more relevant, the models themselves are based on economic factors and do not account for changes in either the types of materials used or the ways they are used. In short, the committee believes that the current modeling methodology, while technically sophisticated, lacks the specificity to identify actual military materials needs and is a carryover from a previous era.

While defense strategy and planning broadly have adjusted to take into account the changing global political and economic environment, the role of the NDS in this strategy and in DoD's added mission of homeland defense is unclear. The NDS is not configured to be responsive to the current, pressing logistical needs of the military, where new military systems are dependent on very different materials and where surge requirements for high-priority systems may be unmet because of shortfalls in materials and industrial feedstock.

There have been some changes in the law over the years as well as frequent changes in the policy for the stockpile's management and operation. However, it is not clear that any of those changes were based on a structured and deliberate look at weapons-specific materials needs and estimates of their availability. As currently configured, the DNSC has little or no flexibility to make sound materials decisions and implement them. In fact, it is clear their primary activity is to complete the congressional mandate to sell off excess materials in the stockpile and to generate revenue.

The committee is concerned that the national materials stockpile system and its operation are neither timely nor based on current information. There is a lack of precision in translating specific defense demands into particular materials requirements, and the episodic nature of the process is problematic. It was not clear how decisions are made after the models have been run and the results presented to the Office of the Secretary of Defense. It is also unclear how these results are employed.

The NDS does not appear to be integrated into the force structure planning of the DoD. Neither the legislation governing the stockpile, nor the modeling that is conducted to develop stockpile goals, nor the DoD structure for stockpile management are appropriate given today's global and domestic materials sectors or current defense needs. As structured, the NDS does not provide the type of insurance that may be needed in future emergencies, and as a result it is not capable of meeting the pressing needs of the twenty-first century U.S. military.

Conclusion 1: The design, structure, and operation of the National Defense Stockpile render it ineffective in responding to modern needs and threats.

Current Defense Materials Needs

Because this was such a quick study, it was impossible for the committee to specify national defense materials. Neither did the committee, under its charge, analyze the current NDS inventory or the decision that all but two NDS materials should be sold. The committee did, however, discuss—and reports on—materials needs based on the following: its members' own knowledge of global materials availability and demand; the outcomes of previous reports on defense materials needs; and interactions with the defense and materials communities. The committee believes that, no matter if the NDS remains configured as is, evolves, or shuts down, DoD would benefit from a serious near-term effort to capture specific defense materials needs. This effort would not use the approach currently used to set NDS stockpile requirements and goals.

Conclusion 2: The Department of Defense appears not to fully understand its need for specific materials or to have adequate information on their supply.

Ensuring against disruptions to the supply of materials of defense interest would benefit from a well-defined and dynamic model of defense needs that allows identification of critical materials. The committee suggests that this model be based on annual reporting from the services and defense agencies, starting at the procurement level, which identifies strategic and critical materials and the potential vulnerabilities in their supply. It believes the expertise of procurement officers throughout DoD could provide a more useful and pertinent assessment of materials needs than the current reliance on economic modeling alone.

In addition, there remains an urgent need to improve the collection of information—both domestic and offshore—on the availability of these materials. Without such supply information there is no way to develop a rationale credible enough to motivate government intervention in the supply of these critical materials. The current efforts of the U.S. Geological Survey's minerals information team are essential, but the committee believes that further investment may be needed to expand data collection capabilities.

Conclusion 3: A lack of good data and information from either domestic or offshore sources on the availability of materials impedes the effective management of defense-critical supply chains.

National Need for the Stockpiling of Strategic and Critical Defense-Related Materials

Although the NDS as configured is ineffective, what about the more general need for stockpiling that the committee was asked to consider? Is there a role for the government? As this report notes, the U.S. government does stockpile critical supplies in pursuit of public-good objectives ranging from economic stability to public health as well as national security. But what about stockpiling the kinds of raw materials the NDS has traditionally held?

When the NDS was begun, the suppliers of weapons, munitions, and the like predominantly worked with raw materials from stock. From a supply chain perspective, bulk materials were "near" the manufacturing process. Today's weapons and munitions suppliers are increasingly integrators of systems, as opposed to fabricators, and the supply chain that feeds them has become a network of global and "distant" suppliers and manufacturers. The supply chains themselves have become increasingly interconnected, with supplier and vendor networks spanning the globe. This kind of diversification of suppliers can reduce risk by introducing redundancy into the supply chain. It is a reasonable policy position that the advent of global supply of materials—and even parts—to industries manufacturing DoD systems reduces the risk of "dangerous and costly dependence," the term used in the law defining the purpose of the NDS. Indeed, the committee heard from DoD that in the 1990s the Department believed the more globalized supply for defense systems, components, and raw materials would mitigate the risk of dangerous and costly dependence, in comparison with reliance on an entirely domestic market, especially when there was a stated willingness to pay any price required for defense-related raw materials.[5] Such a policy position seemed to be justified as raw materials became more available in the 1990s. However, the committee became convinced during the course of the study that the emerging greater demand from large developing economies, the recent decline in the capacity of U.S. industry to supply and process raw materials for defense systems, and the continuing increase in the nation's dependency on foreign sources for materials call for a fresh assessment of the risk and a new policy response.

The committee also became convinced that notwithstanding the ineffectiveness of the current configuration of the NDS, there remains a role for the federal government in the active management of the supply of materials for defense systems. Having considered which tools, in addition to or instead of a stockpile, could help to assure a continuing supply of materials, the committee concluded that a whole new approach was required. It found that the private sector—focused as it is on agility and efficiency, and having been directly impacted by global materials availability—has embraced the concepts of supply-chain management. Where private sector stockpiles of industrial materials, or parts, are deemed absolutely necessary, they are used, but only sparingly. In contrast, the committee made the following observations about the current system for assuring supply for the military, which is centered on the NDS:

- What appears to be missing from the current approach is an ability to apply modern supply-chain management techniques to the supply of defense-critical materials using adequate data on both specific defense materials needs and their global availability.
- Identifying and quantifying the potential risk of a supply chain disruption is complex and requires a much more sophisticated analysis capability than the present approach to modeling NDS materials requirements.
- While DoD has begun to use a logistics system that embraces modern supply chain concepts for warfighting items, the committee found no evidence that such an approach extends beyond the component level to the level of the strategic and critical materials identified by analyzing the needs of specific military systems.

[5]In the case of materials, the issues surrounding price and supply are interesting. The committee notes that the dynamics of the availability of a material are much different, depending on whether it is a primary product of a mineral deposit (such as copper); a by-product (such as molybdenum); or a tertiary product (such as rhenium). The prevailing philosophy, in the commercial world, is that as prices rise, more supply is created. While generally accurate for primary products, it is not the case for secondary and tertiary products.

- As the worldwide stock of raw materials decreases and demand sharply increases, the current system fails to make better use of materials from recycling.
- Policies to mitigate reliance on foreign sources—including import restrictions, Buy-American statutes, and so on—assume that alternative domestic sources of materials are available. Where they are not, these policies may be counterproductive.
- The current system is limited to holding a stockpile, despite the broader array of powers and policy tools that DoD could use to manage supply threats. At least some specific objectives might be addressed more effectively through use of one or more alternative policies, rather than relying on a stockpile.
- Today, U.S. defense and commercial supply chains are mutually dependent on global economic dynamics, but the current stockpile system does not adequately take into account the reality of modern supply chains or their management.

In summary, the committee's analysis, outlined here and described in detail in the report, identifies a potential for disruption in the supply of materials and minerals critical to the U.S. military. In the committee's judgment, foreign dependence is not, per se, a cause for concern. But it may become so when combined with concentration of supply, political instability in the source regions, and greater competition for mineral resources across the globe. The new threat environment includes threats against economic targets from nonstate actors. The risk of supply interruption arguably has increased or, at the very least, has become different from the more traditional threats associated with the more familiar ideas of war and conflict. The decrease in the U.S. percentage of world consumption calls into question our historical ability to command supply in times of shortage. The modern context calls for a modern response.

Conclusion 4: Owing to changes in the global threat environment and changes in the U.S. industrial base, the emergence of new demands on materials supplies, the ineffectiveness of the National Defense Stockpile, and the resultant potential for new disruptions to the supply chains for defense-critical materials, the committee believes there is a need for a new approach in the form of a national defense-materials management system.

RECOMMENDATIONS

There are several policy and supply chain management tools to assure the continuing supply of materials for defense needs. Indeed, for each material, a strategy to supply a need that becomes critical might rely on multiple tools either simultaneously or sequentially depending on the circumstance. Each tool is partially a substitute for the others, and this redundancy can better assure supply. The management of any supply chain system for critical materials must also be dynamic and based on knowing which materials are needed, how much of each, and whether substitutes are available for each material. In addition, the framework for a materials management system needs to reflect current geopolitics and take into account that U.S. defense and commercial supply chains are mutually dependent on one another and on global economic dynamics. All of these issues interplay in a way that demands a systematic and coordinated policy response.

Recommendation 1: To meet the national strategic objective of assuring the timely availability of materials necessary to maintain the national defense capabilities of the United States into the foreseeable future, the Secretary of Defense should establish a new system for managing the supply of these materials.

The basis for the committee's recommendation for a new systematic approach is that planning and action to build a robust supply chain can mitigate the risk of surges in requirements and unexpected shortfalls in inputs. It can also facilitate a response based on the rapid and effective insertion of new substitute materials and manufacturing methods. One significant vulnerability is the potential inability of the military to respond to shortfalls in supply, but a more detailed analysis of the materials supply chain for each military system would help to mitigate risks to mobilization. Developing a robust system is a considerable task as new materials and technology are developed and eventually introduced into military systems and old materials become obsolete and noncritical.

The committee has concluded there are lessons to be learned from the private sector, lessons that are being applied elsewhere in DoD but, it appears, not to the management of raw materials supply, at least so far. Private corporations have adopted strategies giving them the flexibility to offset supply risks, including detailed risk analyses and contingency sourcing plans. Some of the techniques include developing multiple sources, deepening supplier partnerships, and investing in research on recycled materials or substitute materials.

Looking at the general case, the committee notes there are at least three complementary ways for mitigating risks: (1) assess the risks in order to make better informed decisions on managing them (for example, deciding if stocks need to be held); (2) spot vulnerabilities in the supply chain and redesign it to eliminate or mitigate them before events occur; and (3) design and manage the supply chain to be more resilient to disruption. Weaknesses in the supply chain may not always be apparent, a priori; they often reveal themselves only when a system is exercised, such as in wartime.

More active management could uncover supply chain risks by analyzing supply chain disruptions to gain insight into causal factors or systemic issues. Supply choke points or surge demand response issues may point to the need for holding greater inventory at various stages of the process. Holding a stockpile might be one of many tools available to a defense-materials management system, perhaps a tool of last resort. It is a tool that other governments are using but that industry uses only when absolutely necessary. When deciding which policy tools are appropriate for meeting the strategic objective for any material, if a stockpile is being considered it will be important to take into account (1) the quality of the material, how it may degrade, and if its usefulness could diminish over time; (2) how long it would take to get a material to where it is needed; and (3) the total costs of supplying, storing, and maintaining the material.

An effective system to assure the supply of critical materials for defense would have to be a cross-service one. In this regard, the committee notes that a recent action of the U.S. Congress could help establish such a cross-DoD system. Section 843 of the John Warner National Defense Authorization Act for Fiscal Year 2007 (Public Law 109-364) directed the Secretary of Defense to establish the Strategic Materials Protection Board (SMPB) to

> (1) Determine the need to provide a long-term domestic supply of materials designated as critical to national security to ensure that national defense needs are met;
> (2) Analyze the risk associated with each material designated as critical to national security and the effect on national defense that the nonavailability of such material from a domestic source would have;
> (3) Recommend a strategy to the President to ensure the domestic availability of materials designated as critical to national security;
> (4) Recommend such other strategies to the President as the Board considers appropriate to strengthen the industrial base with respect to materials critical to national security; and
> (5) Publish not less frequently than once every two years in the Federal Register recommendations regarding materials critical to national security, including a list of specialty metals, if any, recommended for addition to, or removal from, the definition of 'specialty metal.'

At the time of writing the Strategic Materials Protection Board (SMPB) is being established. The committee understands that the initial driver for the SMPB was the implementation of policies related to "specialty metals"—such as the mandate contained in the so-called Berry Amendment that titanium and the various steel and metal alloys used by defense contractors be made in the United States.[6] Nevertheless, there appears to be no reason why the Secretary of Defense could not take

[6]See http://thehill.com/business--lobby/specialty-metals-industry-clashes-with-defense-giants-pentagon-2006-05-16.html. Accessed August 2007.

a broader—and, indeed, very useful—view of the role of the SMPB. It could serve as the interservice mechanism for coordinating a materials management system.

The committee is well aware that a new system at DoD, and presumably a new but related defense organization, might not solve this problem if it is not a higher priority for the department than the NDS has been in recent years. The committee believes that while the need for a fresh approach is real, the new system will fail without adequate political and financial support for facilitating communications between the various stakeholders within DoD and the services, including the defense planners.

Notwithstanding any future decisions by the Secretary of Defense on how to implement a new system, the committee was asked to provide some general operational principles. With that in mind, the committee offers the following recommendation.

Recommendation 2: The operation of a system for managing materials needed for national defense should be guided by the following general principles:

- **Establish an ongoing analytical process to identify materials that are critical to defense systems. The analysis should include gathering information on short-term and long-term needs for primary and secondary (component) materials. The process could include a system of annual reporting from the services and defense agencies, starting at the procurement level, which identifies strategic and critical materials and the potential vulnerabilities in their supply.**
- **Integrate the ongoing operation of the new system with current defense planning.**
- **Set a flexible policy framework that is integrated with the full set of legislation and policies governing the procurement of defense-related systems from U.S. contractors.**
- **Use all available tools to support and stabilize robust supply chains in the increasingly changeable and global environment for materials supply, including the holding of a materials inventory that would serve as a flexible, continuously changing buffer stock with constant and timely management for restocking and balance.**
- **Provide the option of partnering with private industry as well as options for outsourcing and offshoring.**
- **Provide an appropriate and robust information system and forecasting tools.**
- **Solicit advisory input from industry, academia, and other stakeholders, as appropriate, accompanied by communicating with stakeholders and the**

public on the general status and activities of the materials management system.

- **Evaluate recycling and substitution as additional sources of key materials.**
- **Perform risk assessments that take into account present and future environmental constraints on some defense material availabilities.**

As discussed earlier, no matter what the future holds for the management of the supply of defense-critical materials, there is an urgent need to improve the collection of information—from both domestic and offshore sources—on the availability of materials for defense needs.

Recommendation 3: The federal government should improve and secure the systems for gathering data and information—both at home and abroad—on the availability of materials for defense needs. It must be able to obtain accurate data on

- **The geographic locations of secure supplies of critical materials and of alternative supplies;**
- **The potential for market and geopolitical disruptions as well as logistical and transportation upsets and the risks posed by them; and**
- **The use of materials in defense applications, in the nondefense industrial sectors of the United States, and in the rest of the world's large commodity-consuming nations.**

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2

Historical Context

The concept in the United States of stockpiling important raw materials for military use predates the establishment of the National Defense Stockpile (NDS) by quite some time. The supply shortages experienced during World War I led to the establishment in 1922 of the Army and Navy Munitions Board (within the War Department) to plan for industrial mobilization and procurement of munitions and supplies.

Since then the history of stockpiling materials for military needs in the United States has been punctuated by several reports and reviews that considered many of the same issues being considered in this report, including the relative importance of military and civilian requirements, the scenarios used to define those requirements, the balance between foreign and domestic suppliers, the role of U.S. industry in meeting wartime needs, and the responsibilities of government agencies in the management of the stockpile. A detailed chronological exposition of this history can be found in Appendix A; below is a summary of the history along with a history of acquisitions and releases from the stockpile.

THE HISTORY OF STOCKPILE POLICY

Fluctuations in stockpile size, its management by different agencies, and the impact of different legislative actions on the policy reflect the changes in planning goals over time for the NDS. The committee believes that understanding this history is essential for finding a way to ensure the future supply of military-critical materials.

World War II and the Korean War Period

The Naval Appropriations Act of 1938 and the Strategic Materials Act of 1939 created and provided initial funding ($100 million) for a stockpile of strategic raw materials. Threatened by the potential loss of imports as a result of Japanese conquests in Asia and possible war in Europe, the Army and Navy Munitions Board (established in 1922) developed a list of 42 strategic and critical materials needed for wartime production (Snyder, 1966). By December 1941, $70 million had been appropriated by Congress and $54 million worth of materials had been acquired (Greenwood, 1994). Of the 15 materials in the stockpile during World War II only three were from domestic sources. Between 1942 and 1944, six materials were released for military needs and a seventh, under contract, was redirected before reaching the stockpile, by Executive Order of the President (War Department and Navy Department, 1947).

The first major post-World War II congressional debate on stockpiling began in 1946. The Congress considered the purposes of the stockpile (military versus civilian), the acceptable sources of materials (domestic versus foreign), and appropriate policy and management methods. The resulting legislation, the Strategic and Critical Materials Stockpiling Act of 1946, amended the Strategic Materials Act of 1939 and provided for the Secretaries of War, Navy, and Interior, acting jointly through the agency of the Army and Navy Munitions Board, to be authorized and directed to determine which materials were strategic and critical and to determine the quality and quantity of such materials that were to be stockpiled (Snyder, 1966). The Secretaries of State, Treasury, Agriculture, and Commerce were to cooperate in this effort. The 1946 law established many of the principles by which the NDS operates today. It authorized the appointment "to the fullest extent practicable" of industry advisory committees. The Buy-American Act of 1933 would apply to purchases. Purchases of materials would be done by the Procurement Division of the Treasury Department, which subsequently became the Bureau of Federal Supply. The law called for the storage of materials on military and naval reservations and for the refining, processing, and rotating of materials. It authorized the disposal of materials on 6 months' notice in the Federal Register and notice to Congress but said also that except for reasons of obsolescence no materials might be disposed of without congressional approval. And, finally, the law established the Presidential authorization that was required for the release of materials.

In a further development, the National Security Act of 1947 created a civilian mobilization agency to advise the President and gave it responsibility for the coordination of military, civilian, and industrial mobilization, including the policies establishing adequate reserves of strategic and critical materials and for the conservation of these reserves (Snyder, 1966). And in 1950, following a White House National Security Council assessment, a process was established for identifying stockpile requirements in the case of an extended conventional war with a 3-year industrial/military mobilization. In the same year, the North Korean invasion of South Korea led Congress to quickly appropriate $2.9 billion over a 6-month period for stockpiling materials, and the planning requirement objectives jumped from $4.0 billion to $8.9 billion (Snyder, 1966). In 1949, the Bureau of Federal Supply was transferred from the Treasury Department to the newly created General Services Administration (GSA).

By December 1952, the inventory value of the stockpile was $4.02 billion (Munitions Board, 1953). As many as eight materials were released between 1951 and 1953 for defense purposes under 12 Presidential orders (Gutchess, 1969). President Eisenhower consolidated mobilization functions within the government in 1953 and the Munitions Board transferred the stockpiling program to a new agency, the Office of Defense Mobilization, thereby putting stockpiling activity under civilian control. The responsibility for determining military materials requirements was transferred to the new Assistant Secretary of Defense for Supply and Logistics (Snyder, 1966). During that period stockpile requirements were based on a new 1-year's-normal-use criterion, and imports were permitted from Canada and Mexico only. The Office of Defense Mobilization reported in 1956 a $10.9 billion total value for new stockpile requirements, of which there was $4.7 billion in inventory (Office of Defense Mobilization, 1956).

Cold War Years

During the mid-1950s, with the cold war era well under way, military planners began to examine new scenarios for a nuclear conflict of short duration. These new scenarios affected the stockpile-oriented analysis of industrial mobilization and industry's need for materials and led to a reduction in the quantities of materials needed for the stockpile. A revised plan developed in 1958 was based on a 3-year war instead of a 5-year war. It allowed the disposal of excess materials from the stockpile only if such activity did not disrupt U.S. domestic markets or affect foreign relations. In 1959 an advisory committee of the Departments of Commerce, State, Interior, Agriculture, and Defense was established to review disposal plans.

In the 1960s, defense planners calculated their risk analyses based on the ability to respond to two and one-half conflicts at one time—that is, war with the Soviet Union in Europe, war with the Peoples Republic of China in Asia, and a "half-war" with another regional state, in this case Vietnam. In 1962 President Kennedy announced that he was astonished to find that the stockpiling program had accumulated $7.7 billion worth of materials, an amount nearly $3.4 billion greater than estimated wartime needs (Snyder, 1966). The Executive Stockpile Committee was created under the White House Office of Emergency Planning (OEP) to examine the disposal of strategic and critical materials. A congressional investigation in 1962 and 1963 examined the operations of the stockpile in open hearings. An interdepartmental disposal committee was established by the director of the OEP in 1963 to develop long-range disposal plans for materials that were no longer required (OEP, 1965). By the end of 1965, disposal sales of stockpile materials had reached $1.6 billion (OEP, 1966).

The Materials Reserve and Stockpile Act of 1965 directed that the national stockpile, the supplemental stockpile, including the Commodity Credit Corporation stockpile, and the Defense Production Act inventory be combined into the National Stockpile, a single stockpile chartered to hold all the required strategic and critical materials and with a long-range disposal plan to reduce the inventory of excess materials.

In this same time period worldwide shortages of some materials affected U.S. industry support of defense needs and several materials were released from the stockpile, with Presidential approval, to stabilize supply. In February 1966, the President authorized the release of quinine sulfate for use in Vietnam to combat malaria, and later that year copper and nickel were released under Presidential order. (Box 2-1 discusses releases from the stockpile in detail.)

In 1973, the NSC reevaluated the stockpile and revised the basis for developing new goals or requirements for each material: (1) Materials would be used only for defense purposes; (2) conflicts in more than one theater (Europe and Asia) could be fought simultaneously; and (3) imports of supplies would be available for all years of the national emergency. Then in 1976, the President issued new guidance on stockpile policy, reintroducing essential civilian needs as a criterion and adjusting the military scenario to support a major war over a 3-year period, with the assumption of full-scale industrial mobilization and increased materials demands. An annual materials plan (AMP) that would cover any acquisition or disposal of excess materials was also mandated.

In 1979 Congress passed the Strategic and Critical Materials Stock Piling Act, the second major revision of the original 1939 legislation. Stockpile administration and policy functions were transferred from the GSA to the newly created Federal Emergency Management Agency (FEMA). The storage, maintenance, upgrade, purchase, and sale functions remained with the GSA. In addition the National Defense Stockpile Transaction Fund was established in the Treasury Department to receive money from sales. From August 1979 through September 1988, total net receipts of nearly $1.2 billion were credited to the National Defense Stockpile Transaction Fund. The new law also insisted that stockpile requirements be based on a total mobilization of the economy of the United States for sustained conventional war on a global scale lasting at least 3 years.

A FEMA analysis in 1980 estimated stockpile needs to be on the order of $20 billion. In 1982, in response to a Presidential directive, the GSA initiated a long-term program to upgrade chromite and manganese ores to high-carbon

BOX 2-1
Summary of Releases from the NDS

- *1942-1944*. Six materials were released for military needs, and a seventh material (which was under contract but not yet in the stockpile) was redirected.
- *Korean War*. About $60 million worth of materials were released between 1951 and 1953 for defense purposes. In addition, large quantities of materials on order for the stockpile were diverted to meet industry needs.
- *1952, 1956*. Mercury was released in 1952 and 1956 for use in the atomic weapons program.
- *1964*. Because of supply shortages, Congress authorized emergency sales of antimony, lead, and zinc, and the President approved the release of copper to relieve industry hardship cases.
- *1965*. The President authorized copper to be released in the interest of common defense (OEP, 1966) because of a worldwide shortage, thus serving as an economic stabilizing influence. Under current law, the President cannot release materials for economic reasons.
- *1966*. Quinine sulfate was released for use in Vietnam to combat a strain of malaria that resisted the synthetic drug being used and two additional releases of copper "for purposes of the common defense" (OEP, 1966).
- *1969*. Nickel strikes against the two largest world producers of primary nickel cut nickel availability, and the defense industry began to suffer. Nickel was then released for use in defense production.
- *1979*. Chrysotile asbestos was released to DoD because the one operating mine in Canada had been depleted of reserves and the only other mine in the world, in Zimbabwe, was not producing.
- *1996*. The U.S. Congress in the 1996 National Defense Authorization Act directed the release of up to 250 short tons of titanium sponge to the Secretary of the Army for use in the weight reduction portion of the main battle tank upgrade program.

ferrochromium and high-carbon ferromanganese. This program was aimed at sustaining a U.S. ferroalloy furnace and processing capability vital for industry supplying the national defense.

In the mid-1980s, the NSC under the Reagan administration once again commissioned a stockpile requirements study that declared most of the stockpile inventories unnecessary. This determination was in direct conflict with the prevailing thinking of Congress and several federal agencies, and in December of 1987, Congress directed DoD to take over the NDS, including requirements assessments.

1988 to the Present

In February 1988, Executive Order 12626 designated the Secretary of Defense to be the National Defense Stockpile Manager, and the Defense National Stockpile Center (DNSC) was established as a field activity within the Defense Logistics Agency to manage the operations of the stockpile program (Department of Defense, 1988). The civilian agencies retained a role only on the advisory committees. These events drove changes in the methodology for requirements assessments, an effort led by the Institute for Defense Analyses (IDA).

While the methodology for modeling requirements was improved, the assumptions for the modeling in the late 1980s remained limited. These assumptions, based on the 1979 Stockpiling Act, included a 3-year war scenario and considered that apart from U.S materials suppliers, only Canadian and Mexican suppliers could be considered reliable.

Nonetheless, IDA made modeling the requirements more quantitative by utilizing econometrics to determine supply and demand for NDS materials. This enabled a range of policy options for NDS to be explored and was the framework for evaluating stockpile requirements as DoD planning guidance began to change in 1989, when the Cold War ended and foreign sources of materials were deemed more reliable.

According to the annual NDS reports, the stockpile goals and holdings peaked in 1989, when the NDS contained 91 line items in 62 materials classifications. The total value of the NDS that year was $9.6 billion. Eighty-four of the ninety-one materials were listed as stockpile goal materials and accounted for virtually all of the $9.6 billion value. Although approximately $1.5 billion of the 1989 NDS value was associated with materials held in excess of the identified NDS goals, not all the materials goals in 1989 were met by NDS inventory. To meet those goals would have required the purchase of 40 items valued at $12.5 billion, yielding a total value of stockpile goal materials of $20.6 billion. Of the $12.5 billion shortfall, nearly $10.5 billion was for aluminum, copper, lead, nickel, platinum, ricinoleic/sebacic acid, titanium, and zinc. The stockpile had been deficient since before 1980 in all but one of the 40 materials identified.

The General Accounting Office (GAO) commented on this in a 1992 report, which noted that when January 1991 prices were used, the variations in proposed goals ranged from more than $16 billion in 1979 (the FEMA study) to about $600 million in 1985 (the NSC study), to over $5 billion in 1991 (the IDA/DoD assessment), and, finally, to $3.3 billion in 1992. A year previously, a report from the DoD Inspector General (IG) concluded that the process for determining the types, quantities, and qualities of materials to be acquired and retained in the stockpile needed improvement (DoD, 1991). The audit also found that improvements were needed in the acquisition and disposal of materials. Specifically, the IG recommended that DoD do three things:

1. Base future stockpile goals on a more realistic force level; such as the programmed force; use domestic production capacity from new and reopened facilities; and consider foreign production sources other than Canada and Mexico during a crisis.
2. As provided for in Section 10(a) of the Strategic and Critical Materials Stockpiling Act, establish and institutionalize an interagency advisory committee in coordination with the Departments of Commerce, Interior, and State, to be composed of government experts and to provide information on the civilian and industrial tiers that affect the materials requirements generation process and to assist in the computation of requirements for materials that cannot be quantitatively modeled.
3. Include in the charter of the interagency committee specific responsibilities to assimilate the information necessary to formulate stockpile requirements and to prioritize the stockpile actions regarding those requirements.

One of the most restrictive aspects of the methodology for setting NDS requirements and goals setting was the statutory requirement that the criteria include the ability to sustain a global conventional war lasting at least 3 years and involving total mobilization of the economy. In its response to the IG's 1991 report, DoD noted that it had previously suggested eliminating this criterion, but the relevant legislation was not forwarded to Congress. DoD also noted that in addition to Canada and Mexico, countries in the Caribbean basin would be included as reliable sources in the process to define the 1991 requirements.

Concomitant with these developments came the fall of the Berlin Wall and the recognition that U.S. defense planning, strategizing, and force structure would need fundamental realignment. The new approach concentrated on the need to address regional conflicts while maintaining a minimal force and preserving a hedge capacity to rebuild defenses for global warfare in the event of a resurgent superpower rivalry. A new defense strategy was outlined in the 1992 National Military Strategy (NMS),[1] and with changes in the geopolitical climate came a significant reevaluation of the reliability of foreign sources of materials beyond just the countries in the Caribbean basin. With the changing defense posture came a moratorium on stockpile purchases in 1992 as threat scenarios and country reliability estimates changed—and as DoD budgets were cut. These changes significantly reshaped policy toward the NDS.

In 1992, the Assistant Secretary of Defense testified before Congress that because of the changing military scenario, stockpiled materials requirements had been reduced in value to $3.3 billion (versus $7.1 billion in inventory) (McMillan, 1992). In its National Defense Authorization Act for FY1993, Congress responded to DoD's recommendations by authorizing the disposal of large quantities of 44 NDS materials (out of the 84 on the stockpile list) (DoD, 1993). Included in the

[1]Available at http://handle.dtic.mil/100.2/ADA338837. Accessed June 2007.

same 1993 legislation was an amendment to the Strategic and Critical Materials Stockpiling Act that said the NDS's only purpose was to serve the interest of national defense. It was not to be used for economic or budgetary purposes. The law further required that the AMP submission to Congress detail the maximum quantity of each commodity to be bought or sold in the fiscal year and that the AMP also report on the projected domestic or foreign economic effects of such transactions.

From FY1992 through FY2006, $6.1 billion worth of materials were sold. Since 1993, when the main sales program began, Congress has earmarked part of the funds for specific revenue goals and for particular military programs. Since then, the essential framework for modeling of stockpile requirements has remained largely unchanged (see Chapter 3 for a detailed description of the models used today). As of May 2007, the NDS inventory contained 28 materials valued at about $1.1 billion. With large reductions in the types and quantities of materials, the DNSC has significantly reduced the number of facilities for warehousing materials. Under the current plan, by the end of FY2007, the stockpile will have three consolidated storage locations and a total workforce of 65 (DoD, 2006).

CLOSER LOOK AT RELEASES, ACQUISITIONS, AND UPGRADES OF MATERIALS IN THE NATIONAL DEFENSE STOCKPILE

The specific materials and quantities to be held in the NDS must be authorized by the President. The law requires the President to determine the quality and quantity of each strategic and critical material to be acquired, and the form in which it will be acquired. The President's determinations must be made on the basis of national defense requirements (including essential civilian needs in times of an emergency) rather than for short-term economic or budgetary purposes. The President must inform Congress in writing of any proposed changes to stockpile quantities 45 days before making the change. The President may also authorize the rotation or upgrading of the materials held in the stockpile, to assure that they are suitable for use in an emergency. Similarly, the President may authorize the release or disposition of materials in the stockpile at any time, provided the material release is needed for the national defense in time of declared war or during a national emergency.

Figure 2-1 shows that since 1997 there have been no acquisitions of materials or upgrades to the materials already in the NDS. Releases from the stockpile have been very limited, as shown in Box 2-1.

The President may also authorize the disposal of materials in the stockpile that are deemed to be in excess of requirements or at risk from deterioration.

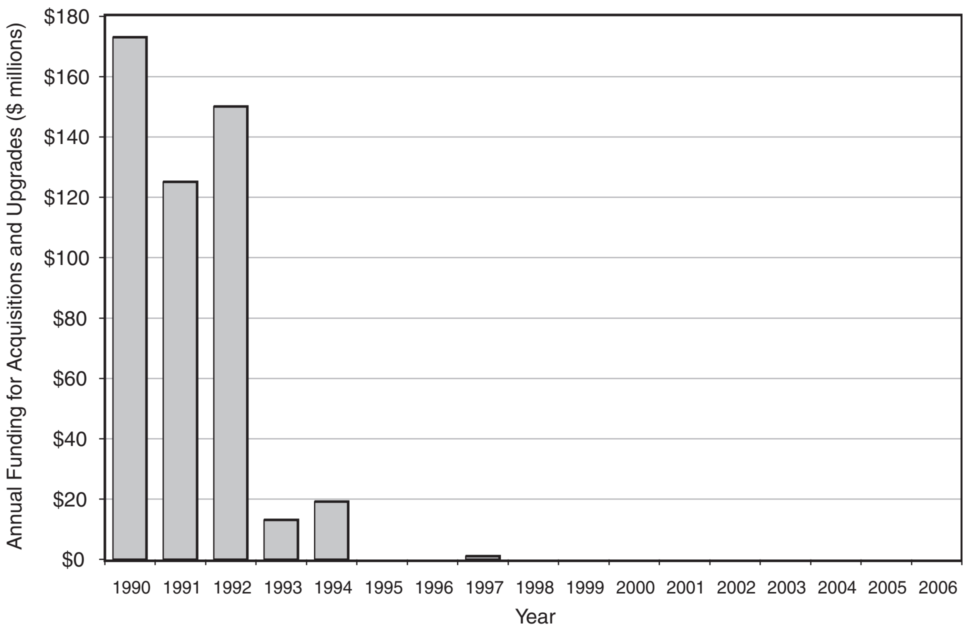

FIGURE 2-1 Annual funding for acquisitions and upgrades. Data taken from DNSC annual materials reports.

Since 1992, changes in defense requirements and supply assumptions have greatly reduced the stockpile requirements, and most of its content has been deemed to be in excess. As mentioned above, Congress instructed DoD to sell off this excess. Such a sale requires specific enabling legislation from Congress. This legislation is based on the AMP submitted to Congress by February 15 of each year, which lists the maximum quantity of each commodity to be bought or sold in the given fiscal year and recommends disposal plans consistent with stockpile requirements. All releases proposed in the AMP must be approved by the Armed Services Committees of the U.S. Senate and the U.S. House of Representatives. Following approval, the AMP becomes effective on the first day of the fiscal year. A revised AMP may be submitted during the fiscal year if significant changes are needed.

Before its submission to Congress, the AMP is reviewed by the Market Impact Committee (MIC), established to advise DoD on the projected economic effects of proposed stockpile transactions in the United States and abroad. The MIC includes representatives from the Departments of Commerce, State, Agriculture, Defense, Energy, Homeland Security, Interior, and Treasury and is co-chaired by representatives of the Departments of Commerce and State. It balances market impact concerns with the statutory requirement to protect the government against avoidable loss. The MIC must consult with representatives of the industries that produce, process, or consume the materials in the stockpile.

From FY1992 through FY2006, these sales totaled $6.1 billion, with another $629 million projected to be sold in FY2007 through FY2009 (Figure 2-2). Most of these revenues were used to offset other government expenditures, to fund the operating costs of the stockpile, or to reduce the deficit, as shown in Table 2-1. As a result of the sales program, inventories dropped from $3.3 billion in FY1999 to $1.1 billion in FY2006. The stockpile is anticipated to reach $629 million by FY2009 (see Figure 2-3), and it is expected that all excess will be sold by 2020.

The NDS was established to provide an insurance policy for the supply of critical materials in time of national emergency. As shown in this section, materials have been released from the stockpile on only 10 occasions in the last 63 years. In recent years, the only NDS activity has been the selling of excess materials to provide funding for other government projects.

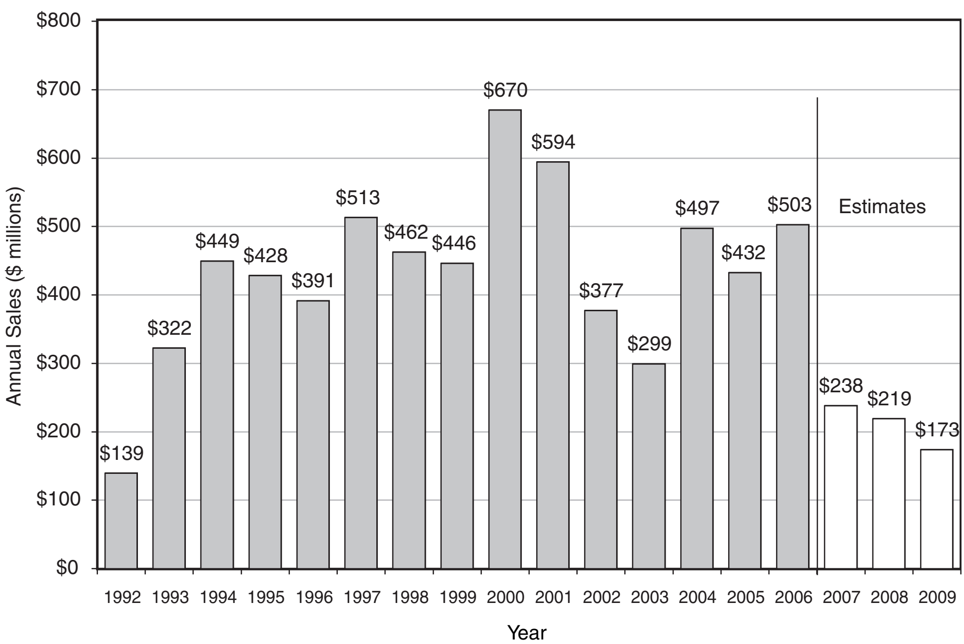

FIGURE 2-2 Annual sales of excess stockpile materials. Data taken from the DNSC annual materials reports and the FY2008 President's Budget Request.

TABLE 2-1 Use of Stockpile Collections for FY1993 Through FY2005 (millions of dollars)

End Use of Stockpile Collections	
Stockpile operations	759
Transfers to other accounts	
Military department operation and maintenance accounts	1,450
Treasury[a]	2,225
World War II Memorial	6
Health and Human Services	92
Increase balance in transaction fund	1,398
Total	5,930

[a]Offset for change in foreign military sales program ($633 million), offset military costs of spectrum change ($426 million), cobalt sales receipts ($133 million), titanium sales receipts ($129 million), and other ($799 million).
SOURCE: Data taken from the DNSC budget documents, Presidential budgets, and relevant authorization acts.

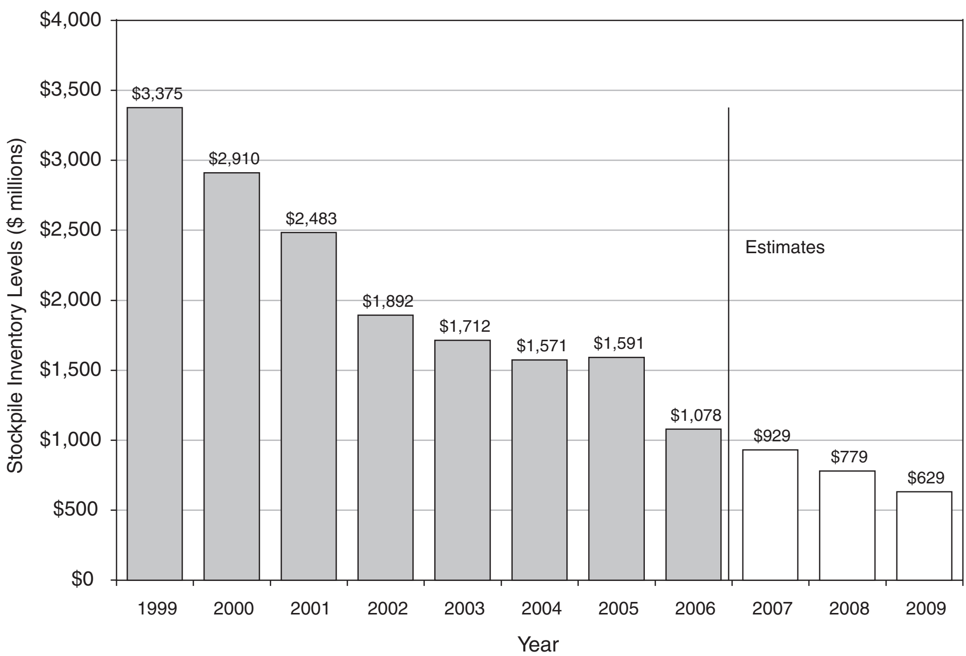

FIGURE 2-3 Stockpile inventory levels. Data taken from DNSC annual materials reports and FY2008 President's Budget Request.

COSTS OF OPERATING THE STOCKPILE

The NDS operations team is funded through the sale of excess materials (designated the National Defense Stockpile Transaction Fund). The funding is used for a number of purposes:

- Acquire, maintain, and dispose of strategic and critical materials,
- Update materials specifications and upgrade existing stockpile materials to current specifications,
- Test stockpile materials,
- Study future material and mobilization requirements for the stockpile,
- Contract for materials development and research to improve the quality and availability of materials in the stockpile and develop new materials for the stockpile,
- Improve facilities, structures, and infrastructure,
- Perform environmental remediation, restoration, and waste management, and
- Pay employees and other expenses of the stockpile program, including the cost of employees.

As the size of the remaining stockpile decreases, so does the size of the staff, facilities, and expenses of its operation.

TOOLS TO ASSURE SUPPLY: NOT A NEW QUESTION

It became clear to the committee early in the study that the question of the future of the stockpile was anything but new. Some previous reports asked some important questions about the stockpile, considered alternative ways to assure materials supply, and recommended future actions. Some of those reports are summarized below, because although many of them are decades old, they deal with either the same issues as did this committee or similar ones.

1975 General Accounting Office Report

In 1975 the General Accounting Office (GAO)[2] issued the report *Stockpile Objectives of Strategic and Critical Materials Should be Reconsidered Because of Shortages* (GAO, 1975). In it the GAO referred to an earlier report, *U.S. Actions Needed to Cope with Commodity Shortages* (GAO, 1974), where it had noted that shortages of basic commodities were causing serious economic, social, and political problems

[2]Effective July 7, 2004, the GAO's legal name became the Government Accountability Office.

for the United States and other countries around the world. It also noted that the final report of the National Commission on Materials Policy (NCMP)[3] had come to a similar conclusion: U.S. materials demands on the rest of the world's supply were growing at a time when other nations' demands were growing even faster (NCMP, 1973). The NCMP report said that in the past the United States had had little difficulty importing the minerals it needed but suggested that the situation might change because of (1) increasing competition for scarce resources and (2) the possibility of actions to restrict supplies and/or increase prices.

The 1975 GAO report noted the NCMP reported that:

> The nation's vigorous industrial and economic growth over the past century has resulted in the highest standard of living in the world. Our complacency, however, has resulted in our failure to develop new material sources as fast as required by the economy. As a consequence, the United States is increasingly dependent upon foreign sources.

The NCMP report concluded that, on the basis of commodity summaries and projections, the gap between U.S. requirements and domestic supply was widening for most of the country's basic materials. Provided that the stockpile was replenished, said the 1975 GAO report, stockpiled materials could be released and used as an alternative to imports as a source of supply, reducing import dependence. Although not a long-term source of supply, it went on to say, the stockpile could be a short-term method of neutralizing economic and/or political crises.

The GAO report concluded that because competition for a finite supply of nonrenewable resources was increasing and because producer boycotts and other restrictions were possible for some resources, the United States might no longer be able to count on importing the quantities of resources it needed. (Stockpile policy at the time did, however, assume that the United States would not be able to import from communist countries or from those involved in a conflict.) The GAO believed this assumption ran contrary to the world resources outlook and that long-range planning would be necessary to deal with the increasing demand for resources. Its report noted that the United States relied heavily on imports of some of the materials that had been authorized for selling off and questioned whether enough thought had been given to their future supply. If long-range planning had

[3]The Resource Recovery Act of 1970 created the NCMP, giving it the charge "to enhance environmental quality and conserve materials by developing a national materials policy to utilize present resources and technology more efficiently, to anticipate the future materials requirements of the nation and the world, and to make recommendations on the supply, use, recovery, and disposal of materials." One finding of the NCMP's 1973 report to the President and to the Congress, *Material Needs and the Environment Today and Tomorrow*, was that in 1972 the U.S. imported $14 billion worth of minerals (including petroleum) and exported $8 billion worth, for a net deficit of $6 billion.

been done earlier, the disposals might never have been authorized. Such planning was particularly important for materials that

- Had no substitutes,
- Were largely imported,
- Were in strong demand, and
- Were susceptible to producer boycotts and other restrictions.

The GAO recommended in its 1975 report that the Secretary of Defense and the National Security Council reevaluate stockpile assumptions to ensure that adequate materials were stockpiled to meet the nation's readiness needs. It also recommended that the then stockpile manager, the Administrator of General Services, use these kinds of data to arrive at new national stockpile objectives.

Finally, the GAO suggested that the Congress might want to consider broadening the strategic and critical materials stockpile concept to release material to meet short-term economic as well as national defense emergencies. Any materials released for economic purposes, the GAO suggested, should be replenished so that all national defense requirements could be met.

1983 Congressional Budget Office Report

A paper by the Congressional Budget Office (CBO) noted that stockpiles were named according to their purposes: defense stockpiles are intended for use during a military emergency, while economic stockpiles are buffer stocks intended to smooth out transient supply disruptions (the Strategic Petroleum Reserve, is an example of the latter) (CBO, 1983). The CBO noted that the NDS was not an economic stockpile—that is, it was not designed to bridge markets during localized interruptions of mineral flows in normal times or to assist in price control. Indeed amendments to the legislation governing the NDS precluded the stockpile from being used for economic proposes.

Looking at the future of the stockpile, the CBO suggested a number of policy options for ensuring materials supplies during national emergencies. The following options make a good short list of the tools government can use:

- Increasing the size and scope of the National Defense Stockpile,
- Building economic stockpiles,
- Subsidizing domestic production,
- Diversifying sources of supply,
- Encouraging exploration for and production of critical minerals on public lands,

- Intensifying metals and materials R&D, and
- Utilizing foreign policy initiatives.

The CBO report noted that the National Commission on Supplies and Shortages, established by President Ford, endorsed the creation of an economic stockpile in its 1976 report. Such a stockpile would be used to supplement mineral supplies when they were disrupted for political or logistical reasons. The CBO suggested that the Congress might wish to consider allowing use of the defense stockpile for that economic purpose during localized disruptions of individual minerals, just as the Strategic Petroleum Reserve was established to bridge oil import disruptions.

Subsidizing Domestic Production Title III of the Defense Production Act authorizes the President to guarantee loans and take other measures to expand production of strategic minerals in the interest of the national defense. During the Korean War, this authority was used to increase significantly domestic production of aluminum, copper, tungsten, and other metals. But this production was achieved at a substantial cost—by 1959, subsidized production acquired by the government at a cost of $1.4 billion was worth only $0.8 billion at market prices. The CBO noted that the disadvantage of this option is its potential cost.

The CBO report noted that diversifying sources of supply assures both U.S. metal-using industries and the economy as a whole that damage from supply contingencies could be contained. Diversification, the report said, would provide alternative supplies during a disruption and lower the chances of a cartel manipulating minerals markets. The CBO noted that U.S. policy traditionally encouraged U.S. investment in resource industries of developing nations, but as such, the application of the policy did not discriminate in favor of investments that represented true diversifications.

The CBO report noted that about one-third of U.S. land area is public land, much of it closed to minerals exploration and development. The CBO report recognized that providing access to these lands was (and remains) controversial, given the inherent tension between development and aesthetic preservation. It suggested that a survey to better define the mineral wealth of public lands (perhaps by the U.S. Geological Survey) could minimize the conflict between wilderness preservation and minerals development.

The CBO report noted that R&D in minerals exploration, production, and applications could limit and had limited U.S. vulnerability to shortages of imported minerals. The report noted the substitution of ceramic magnets for cobalt ones and the development of replacements for metals (graphite comes to mind) as examples of innovations. Federal funds for research on materials, however, are mainly used for research on fuels and renewable resources. The CBO suggested that the Congress might wish to consider legislation to promote R&D for minerals and metallurgical science.

The CBO noted that the international character of minerals flows makes supply vulnerability a foreign policy issue. Even though written nearly a quarter century ago and long before the term "globalization" entered common parlance, the CBO report opined that expanding and diversifying minerals supplies might be best accomplished in the context of the international development agencies, with U.S. leadership. It suggested that a review of foreign policy focused on U.S. concerns about the stability of mineral supplies could suggest diplomatic efforts that would stabilize and diversify mineral imports without significant budgetary costs. New policy initiatives could be implemented through trade agreements or other steps to assure the security of minerals supplies.[4]

SUMMARY

As originally conceived, the stockpile was a kind of insurance policy in support of a major mobilization during a national emergency. Since then, U.S. defense strategy and global threats have changed significantly, especially since the end of the Cold War. Stockpile requirements and NDS inventories have also changed. Later chapters in the present report explore how the dependence on foreign sources has evolved through the beginning of the twenty-first century. Many forums and reviews have considered how the changing threats, defense scenarios, and minerals markets should affect the operation of the NDS. None of those reports brought about any

[4]The committee was also made aware of two relevant reports from the Air War College and the Industrial College of the Armed Forces. The 1994 Air War College report *National Defense Stockpile: Modernization or Suicide?* (Byzewski, 1994) concluded that in many cases close examination of the quality and quantity of each of the materials being offered for sale from the stockpile reveals "sound judgment and logic which appear to fully incorporate national security strategies." The report warned, however, that using "overly optimistic planning factors to assess the availability of minerals which the U.S. relies upon from unstable sources also seems contrary to a strong national defense posture." It suggested that the national investment in the stockpile is comparable to buying an insurance policy, and that if no emergency does arises, there are always those who will say that a 3-year supply of strategic and critical minerals was a waste. A 2004 Industrial College of the Armed Forces (ICAF) report on strategic materials noted that although they account for only a small percentage of the U.S. GDP, materials will be "key to our future economy" and "vital to meeting the security needs of an agile, lightweight force combating new threats in a global war on terrorism" (Industrial College of the Armed Forces, 2004). It noted also that the decision to sell off the contents of the NDS was in keeping with the expectation of only short-duration conflicts into the future. Risk would be minimized, it judged, by the retention of short-term supplies of materials and by arranging for rapid availability of materials from multiple sources on the global market. The ICAF report concluded, however, that the elimination or significant reduction of the stockpile increased the risk in the event of a protracted war or terrorist sabotage of key production sites. It suggested that stockpiling should be constrained to areas where few sources exist since prolonged dependence on a single foreign source poses a risk to national security that varies depending on the relationship with the source country. The report specifically recommended that the government consider stockpiling selected rare earth elements.

visible change in stockpile operations. This committee's report addresses many of the same issues, and its conclusions and recommendations complement those in the earlier reports. One of these issues is whether the NDS as currently structured provides the type of insurance that may be needed in future emergencies.

As a case in point, the following action took place while this report was being written. Because of the urgent need to counteract improvised explosive devices (IEDs) in Iraq, the DoD decided to put the Mine Resistant Ambush Protection (MRAP) vehicle on a fast-track production schedule. To ensure enough armor steel to build such a large number of vehicles, Defense Secretary Gates approved DX rating for MRAP on June 1, 2007.[5] The committee notes that in this particular instance—a real material requirement for a wartime situation—it is doubtful that the NDS as currently structured could solve the problem.

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[5]The Defense Priorities and Allocations System (DPAS) regulations authorize "delegate agencies" to place contracts and orders in support of certain approved programs and requires contractors, subcontractors, and vendors to give precedence to the performance of those contracts and orders over all other contracts and orders, even commercial contracts and orders. Such contracts, subcontracts, and purchase orders are called "rated orders," and they can have one of two ratings: DO or DX. All DO-rated orders support programs that are designated by the secretary of defense as being "of the highest defense interest" and have equal priority with each other and take precedence over unrated orders. All DX-rated orders support programs that are designated by the President as being "of the highest national priority" and have equal priority with each other and take precedence over all DO-rated orders and all unrated orders.

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3

Raw Materials and Minerals Supply

It is important to remember that there are four stages in the life cycle of a mineral: (1) geological mineral deposits are mined and processed into refined materials, (2) refined materials (few if any minerals are economically interesting as mined) are subsequently utilized in either civilian or defense manufacturing industries to produce end products, which are (3) used for a certain period of time before they become obsolete and (4) enter waste management where they are either recycled or discarded in landfills. Trade in all products along the cycle arises from changes between countries in terms of their resource endowment, industry structure, and consumer preferences. This chapter analyzes changes in different parts of the mineral cycle.

The National Defense Stockpile (NDS) is an inventory of raw materials held in various forms such as ingots, pressed powders, and so on. These materials have been held (and, more recently, sold) against the backdrop of a global minerals market that since the 1970s and the height of the cold war has changed dramatically on both the supply and the demand side. These changes can be considered in five categories:

- Increasing demand for minerals from both industrial and developing countries,
- Dramatic changes in where minerals come from,
- Volatile markets and pricing,
- Corporate consolidation in the global mineral industry, and
- Increased vulnerabilities in the mineral supply chain.

Part of the change in the minerals market can be traced to the major shifts under way in globalized world markets and economies in general. Economists have sought to capture these developments by positing the notion of BRIC economies, with the acronym standing for Brazil, Russia, India, and China (Wilson and Purushothaman, 2003). It is predicted that by 2040 the combined economies of the four BRICs will be larger than the combined economies of France, Germany, Italy, Japan, the United Kingdom, and the United States. Emerging market economies, most notably China, have become the dominant materials consumers as their industrial and consumer needs are met. China is also a major supplier of raw materials. The increasing demand has pushed mineral prices up to new highs over the last 10 years (see Figure 3-1).

A recent report of the United States Geological Survey (USGS, 2007) states as follows:

> The extent to which economic growth in developing countries, especially China and India, can lead global economic growth will be of increasing significance. China's economic development has been the main impetus for higher commodity prices in the last few years. If China is able to continue that development to the level of Europe, Japan, and the United States and if India also continues to develop its economy, mineral consumption is likely to continue to grow for a number of years.

Meanwhile, as discussed later in this chapter, mining production in the United States has seriously eroded over the past three decades. Perhaps even worse is the situation for mineral processing, with domestic processing plants and smelters having been closed. Some material mined in the United States has to be sent abroad for smelting or other processing. The result is an increasing dependence on imported minerals in both raw and processed forms.

The resulting volatility in today's minerals market—in terms of price, supply, and demand— compared to 30 years ago adds complexity and uncertainty to planning, purchasing, and managing decisions, such as those taken by the Department of Defense (DoD) and its contractors in the provision of defense systems. In the seven decades since the National Defense Stockpile (NDS) was established there have been marked changes in who is purchasing and using minerals and metals in the global market and where those minerals and metals are being obtained and processed.

GLOBAL MINERAL USE

The 20th century was characterized by a rapid increase in the wealth of the then industrializing countries—a trend that accelerated from decade to decade in the latter half of the century. Economic data from the International Monetary Fund (IMF) for the years 1950 through 2004 show that in a little more than 50 years, the global economy grew from $7.1 trillion to $56 trillion in constant (inflation

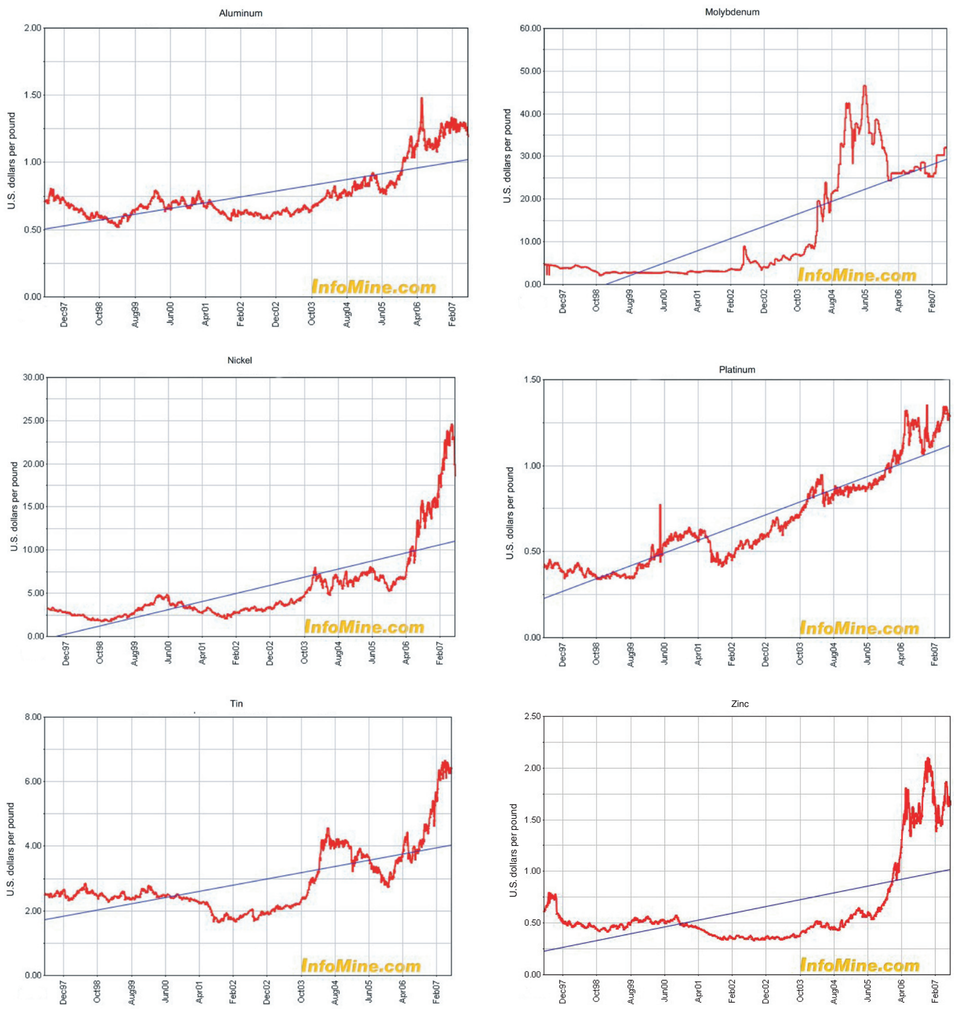

FIGURE 3-1 Price data for aluminum, molybdenum, nickel, platinum, tin, and zinc from 1997 to 2007. SOURCE: Infomine.com.

adjusted) U.S. dollars. This is equivalent to an annual growth rate of 3.8 percent over more than 5 decades. Growth has continued since, with the gross world product in 2006 estimated by the Central Intelligence Agency at $66 trillion.[1]

The demand for minerals (and for energy) grows with the global economy,

[1]See the CIA *World Factbook*, available at https://www.cia.gov/library/publications/the-world-factbook/. Accessed July 2007.

and growth in the 20th century and since was fueled by unprecedented growth in raw materials use on a global scale, with the United States and Europe being the dominant users of raw materials. The output of mines around the world is a good indicator of these changes. During the 20th century, for instance, tin production increased threefold since 1900, and aluminum production grew 3,000-fold over the same time period (USGS, 2007).

More recent data show that since 2000 many developing economies, such as the BRIC economies, have experienced above-average economic growth. IMF data show that annual growth in GDP in emerging market economies over the last 6 years has been two to three times greater than the growth of GDP in industrialized countries.[2] Such rapid growth is being fueled by the greater consumption of industrial minerals.

This increasing global activity can be seen from the history of crude steel production in six countries. Since steel production is a principal user of a variety of alloying elements—such as chromium, nickel, and molybdenum—crude steel production is a good indicator for the use of other materials as well. Figure 3-2 shows that in 1953, U.S. steel production reached 100 million metric tonnes (MT) per year, which is about the current level of production. At that time, China's crude steel production was 1.8 MT per year; by 2006, China was producing 422 MT per year, more than four times as much as the United States. In the last 2 years alone, China added about 150 MT per year to its production capacity.

GLOBAL DISTRIBUTION OF GEOLOGICAL MINERAL RESOURCES

A fundamental factor in the global materials market is that Earth's mineral resources, while vast, are very unevenly distributed geographically. Economically recoverable concentrations are irregularly concentrated in discrete geologic environments around the world. Historically, the minerals industry has focused on world-class deposits (Singer, 1995), which are sizeable and high grade (quality) and have the greatest economic value. These world-class deposits have supplied large portions of the world's industrial requirements over the last century. They include cobalt from the Congo; chromium, platinum-group metals, and manganese from South Africa; tungsten, rare earths, and antimony from China; bauxite from Jamaica; manganese from Ukraine; platinum-group metals from Russia; nickel from Canada; and molybdenum from the United States, to name but a few.

Since many known, most available mineral ore deposits, especially those in Europe and North America, have already been fully utilized or cannot be brought into production owing to environmental concerns, exploration for new sources of

[2] See the IMF *World Economic Outlook Report* at http://www.imf.org/external/pubs/ft/weo/2007/01/index.htm. Accessed July 2007.

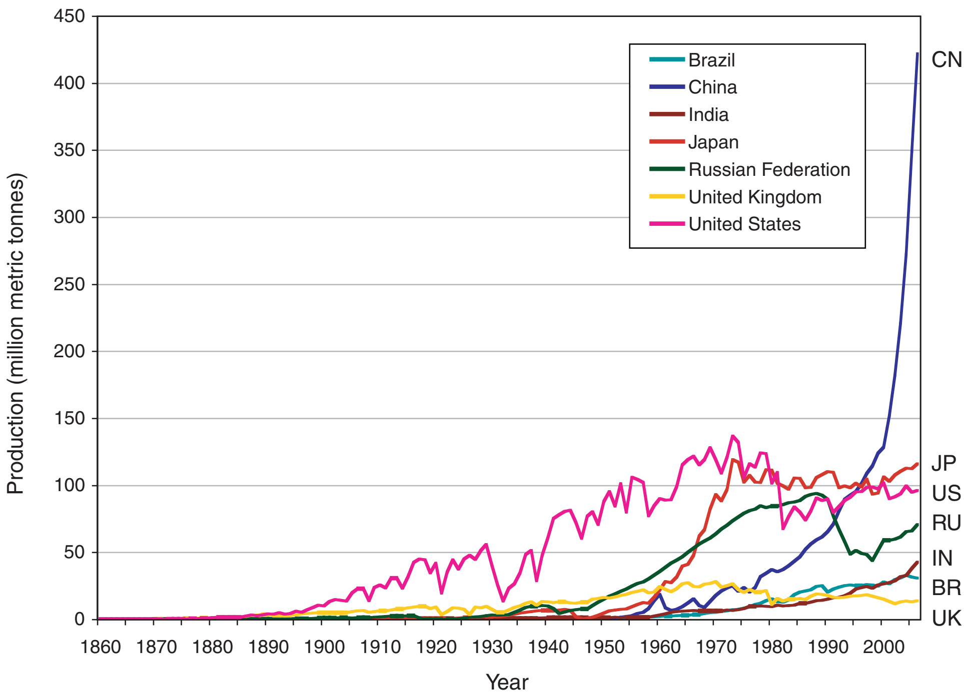

FIGURE 3-2 Annual raw steel production. SOURCE: International Iron and Steel Institute (2007); U.S. Geological Survey (2007). BR, Brazil; CN, China; IN, India; JP, Japan; RU, Russia; UK, United Kingdom; and US, United States.

needed minerals and mining operations will continue to expand to more remote locations around the world. There are many steps needed to bring minerals from these undeveloped sources to the market—exploration, development, extraction, processing, refining, manufacturing, and marketing. All of these steps are expensive and—for geological, technical, economic, sociological, and political reasons—often uncertain and very risky. A mineral deposit can be developed only when the recovery and processing can be done at a profit. As the market value of a particular commodity increases, the economic incentive increases to develop deposits that are either physically or chemically more challenging. Human innovation and technology also influence which deposits can be economically recovered. For instance, the United States is mining much poorer grades of copper and iron than many other countries because a technology advantage makes the mining effort economically competitive. Figure 3-3 shows the average yield of copper from U.S. ore since 1950.

Higher demand and higher prices continue to push mineral production into

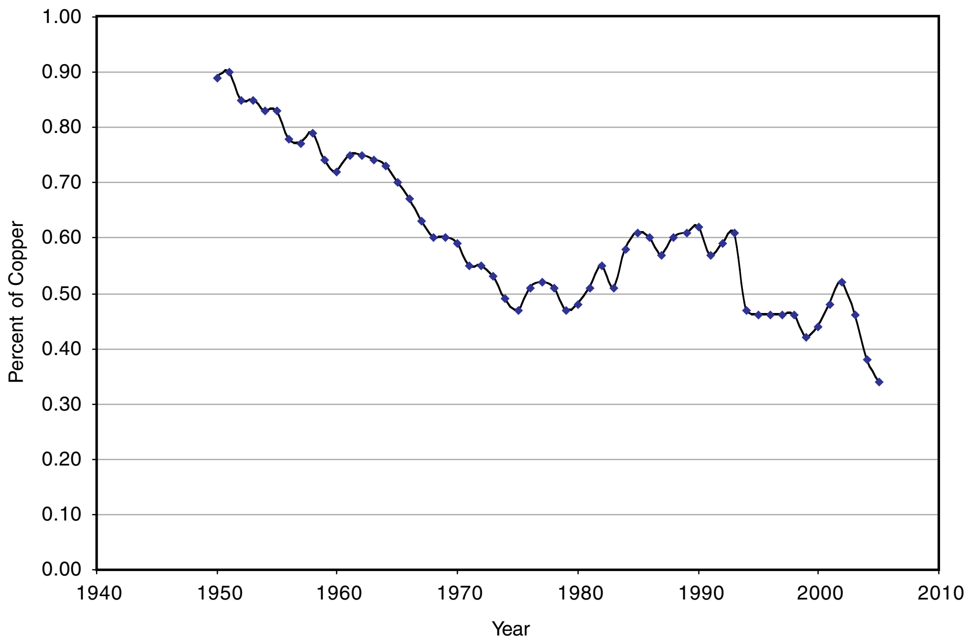

FIGURE 3-3 Average yield of U.S. copper over time. Yield here is defined as the recovery rate from the ore excluding overburden. Yield is used here as a first-order approximation of the average ore grade. Data show the average yield has decreased by half over the last 50 years. SOURCE: U.S. Bureau of Mines and the U.S. Geological Survey.

emerging and undeveloped countries around the globe, bringing higher costs for development and transportation. Overseas sourcing and production also bring new political vulnerabilities if, for example, a foreign government is able to control the export. The rarer or more valuable a particular mineral or material, the more likely it is that some sort of policy will influence its supply. The threat of export cut-offs is particularly burdensome if there is no alternative source, domestic or foreign, of the mineral at a competitive price.

It is important to note another potential source of materials that is largely ignored in the current supply assessments. These is scrap material that could be recycled or reused. A longer discussion of recycling can be found in Chapter 5. The largest U.S. export by weight is scrap metal (steel, aluminum, and copper).

U.S. MINING AND PROCESSING SECTORS

Because mining activities usually follow economic rules and focus on the richest ores available at the time, taking account of the safety and reliability of the potential mining sites, the mineral concentration of mined ores is continually declining. The yield of copper in the United States, reflecting the grade of the copper ore, decreased from 1950 to 2006 from about 0.9 percent to 0.34 percent (Figure 3-3). The decrease in the grade of an ore can have significant implications for the environment and for the mining costs since it can affect waste (tailings) and the energy and water used for extraction and concentration of the mineral, depending on the extraction technique used. Although the United States tends to have fairly competitive operating costs—the U.S. workforce is technically competent and can operate automated systems—mining operations are shifting to countries that are often less developed and have higher grade ores, lower labor costs, and lower environmental standards. As a result, the U.S. demand for minerals is increasingly being met by offshore mining and ore processing facilities. The most striking indicator of this change is the increasing dependence of the United States on imported of minerals to support the domestic economy.

USGS data show that in 1980 the United States depended 100 percent on imports for 4 minerals and 30 to 99 percent on imports for 16 minerals. Twelve years later, in 1992, the United States was 100 percent dependent on imports for 8 minerals and 30 to 99 percent dependent on imports for 22 other minerals. In 2006, the U.S. imported 100 percent of its supply of 17 minerals and over 50 percent of its supply of 45 of the 65 minerals reported (Figure 3-4). The trend is clear: We are in increasingly dependent on importing select minerals and metals to fuel domestic economic activity.

Figure 3-4 shows that the United States obtains critical minerals from many developing countries—Chile, China, Gabon, Guinea, India, Madagascar, South Africa, Ukraine, and so on. Some of these countries have been major mineral sources for decades. Other countries that were previously remote and undeveloped are relatively new sources. As mentioned above, at issue here is not merely a dependence on foreign imports, but whether the foreign countries in question have a history of political instability, hostility, or volatility. The heavy dependence on foreign imports also magnifies the effect of other nations' trade policies—for example, export or investment restrictions—on the U.S. supply chain.

The implications for the United States have been of concern for some time, as concluded by a study (NRC, 1990) that noted as follows: "The United States has consistently maintained that a strong domestic minerals and metals industry is an essential contributor to the nation's economic and security interests" and that the industry "provides the material foundation for U.S. manufacturing." The study went on to say

> the United States is among the world's largest consumers of nearly every metal, much of which is imported. Since many of the world's mineral resources are located in areas where political instability and/or economic manipulation represent a potential threat to supply, it is essential for the United States to ensure some degree of independence

Commodity	Percent	Major Import Sources (2002-05)[1]
ARSENIC (trioxide)	100	China, Morocco, Mexico, Chile
ASBESTOS	100	Canada
BAUXITE and ALUMINA	100	Jamaica, Guinea, Australia, Brazil
COLUMBIUM (niobium)	100	Brazil, Canada, Estonia, Germany
FLUORSPAR	100	China, Mexico, South Africa, Mongolia
GRAPHITE (natural)	100	China, Mexico, Canada, Brazil
INDIUM	100	China, Canada, Japan, Russia
MANGANESE	100	South Africa, Gabon, Australia, China
MICA, sheet (natural)	100	India, Belgium, China, Brazil
QUARTZ CRYSTAL (industrial)	100	Brazil, Germany, Madagascar, Canada
RARE EARTHS	100	China, France, Japan, Russia
RUBIDIUM	100	Canada
STRONTIUM	100	Mexico, Germany
THALLIUM	100	Russia, Belgium
THORIUM	100	France
VANADIUM	100	Czech Republic, Swaziland, Canada, Austria
YTTRIUM	100	China, Japan, France, Austria
GALLIUM	99	China, Japan, Ukraine, Russia
GEMSTONES	99	Israel, India, Belgium, South Africa
BISMUTH	96	Belgium, Mexico, China, United Kingdom
PLATINUM	95	South Africa, United Kingdom, Germany, Canada
STONE (dimension)	89	Italy, Turkey, China, Mexico
ANTIMONY	88	China, Mexico, Belgium
RHENIUM	87	Chile, Germany
TANTALUM	87	Australia, Canada, China, Japan
BARITE	83	China, India
DIAMOND (natural industrial stone)	82	Ireland, Botswana, Ghana, Belgium
PALLADIUM	82	Russia, South Africa, United Kingdom, Belgium
COBALT	81	Norway, Russia, Finland, Canada
POTASH	80	Canada, Belarus, Russia, Germany
TIN	79	Peru, Bolivia, China, Indonesia
CHROMIUM	75	South Africa, Kazakhstan, Zimbabwe, Russia
TITANIUM (sponge)	72	Kazakhstan, Japan, Russia
IODINE	71	Chile, Japan
TITANIUM MINERAL CONCENTRATES	71	South Africa, Australia, Canada, Ukraine
TUNGSTEN	66	China, Canada, Germany, Portugal
SILVER	65	Mexico, Canada, Peru, Chile
ZINC	63	Canada, Mexico, Peru, Australia
NICKEL	60	Canada, Russia, Norway, Australia
SILICON (ferrosilicon)	60	China, Venezuela, Russia, Norway
PEAT	59	Canada
MAGNESIUM METAL	54	Canada, Russia, China, Israel
GARNET (industrial)	53	Australia, India, China, Canada
MAGNESIUM COMPOUNDS	53	China, Canada, Australia, Austria
DIAMOND (dust, grit and powder)	51	China, Ireland, Ukraine, Russia
ALUMINUM	44	Canada, Russia, Venezuela, Brazil
NITROGEN (fixed), AMMONIA	42	Trinidad and Tobago, Canada, Russia, Ukraine
COPPER	40	Chile, Canada, Peru, Mexico
PERLITE	35	Greece
VERMICULITE	31	South Africa, China
MICA, scrap and flake (natural)	30	Canada, China, India, Finland
CADMIUM	29	Australia, Canada, Belgium, Peru
GYPSUM	27	Canada, Mexico, Spain, Dominican Republic
SULFUR	26	Canada, Mexico, Venezuela
CEMENT	24	Canada, Thailand, China, Venezuela
IRON and STEEL	21	Canada, European Union, Mexico, Brazil
SALT	16	Canada, Chile, The Bahamas, Mexico
PUMICE	12	Greece, Italy, Turkey
TALC	11	China, Canada, France, Japan
IRON and STEEL SLAG	7	Canada, Italy, France, Japan
PHOSPHATE ROCK	6	Morocco
IRON ORE	5	Canada, Brazil, Chile, Australia
LEAD	2	Canada, Australia, China, Mexico
LIME	1	Canada, Mexico
SAND AND GRAVEL (construction)	1	Canada, Mexico, The Bahamas

FIGURE 3-4 Net reliance in 2006 on imports of selected nonfuel mineral materials, showing top foreign suppliers. SOURCE: USGS, 2007.

> from foreign control over supply and costs through domestic participation in this industry.
>
> Unless a strategy building on areas of U.S. comparative advantage is pursued, the current competitiveness of the domestic industry versus foreign competitors is likely to be transitory. . . . The competitiveness of the domestic industry must in future depend increasingly on . . . technology. (NRC, 1990, p. 2)

For the last several decades, there has been an ongoing debate regarding the weakening U.S. minerals and metals industry. The number of mining operations, processing facilities, and metal fabricating plants has been on the decline. Numerous studies have examined this trend and the country's increasing dependence on foreign sources of mineral and materials commodities (GAO, 1981; Jordan and Kilmarx, 1979; Kessel, 1990; NRC, 1990; Youngquist, 1990).

The reduction in U.S. mining production has been caused by a combination of economic and social considerations. As the metal content of ores in the United States declines, the cost of mining and processing those ores increases. Increased environmental awareness and regulation have added to the operational costs of mining and have placed social pressure on mining companies to limit operations. For whatever reason a U.S. mining operation shuts down, restarting it in response to supply interruptions could be very time consuming and expensive.

The same is true of mineral processing, where domestic processing plants were also closed for economic or environmental reasons. The NRC report suggested that some of our international competitors did not impose such heavy burdens or else they subsidized the producers who had to implement them (NRC, 1990). The report recommended that in order for the domestic minerals and metals industry to survive, there must be "long-term commitment to a continuing reevaluation of the problems and opportunities facing the industry."

This loss of domestic mineral processing capacity is pertinent to the discussion of stockpiles or reserves of materials important to national security. Should access to overseas mineral processing facilities be interrupted for an extended period, it would be neither quick nor easy to restart domestic operations even for those materials that do exist within our borders, owing to a lack of critical physical infrastructure and experienced mining professionals.

As discussed above, many of the materials the U.S. now routinely imports in large quantities were once produced domestically in quantities sufficient to meet national requirements. Table 3-1 provides data on U.S. primary production, apparent consumption, and world production for eight key commodities. In nearly every case, U.S. demand for the commodity has increased with time, while domestic production has declined, resulting in a greater U.S. dependence on foreign sources and a small U.S. presence on the supply side of the world market.

TABLE 3-1 Data on U.S. Primary Production, Apparent Consumption, World Production, and U.S. Share of World Production for Eight Commodities

Commodity	U.S. Primary Production (MT)	U.S. Apparent Consumption (MT)	World Production (MT)	U.S. Share of World Production %
Aluminum				
1945	449,000	772,000	870,000	51.6
1965	2,498,000	2,850,000	6,310,000	39.6
1985	3,500,000	5,210,000	15,400,000	22.7
2004	2,516,000	6,590,000	29,800,000	8.4
Chromium				
1945	3,800	251,000	318,000	1.2
1965	0	893,000	1,490,000	0.0
1985	0	433,000	3,180,000	0.0
2004	0	555,000	5,380,000	0.0
Copper				
1945	1,010,000	1,650,000	2,110,000	47.9
1965	1,550,000	1,980,000	4,660,000	33.3
1985	1,060,000	2,140,000	7,990,000	13.3
2004	1,260,000	2,550,000	14,600,000	8.6
Lead				
1945	450,000	915,000	1,250,000	36.0
1965	385,000	1,000,000	2,700,000	14.3
1985	487,000	1,130,000	3,390,000	14.4
2004	148,000	1,480,000	3,110,000	4.8
Molybdenum				
1945	14,000	12,200	16,300	85.9
1965	35,100	23,300	44,700	78.5
1985	49,200	17,200	98,400	50.0
2004	41,500	23,900	141,000	29.4
Nickel				
1945	1,050	109,000	145,000	0.7
1965	12,300	156,000	425,000	2.9
1985	4,730	197,000	813,000	0.6
2004	0	212,000	1,390,000	0.0
Tungsten				
1945	2,390	3,060	10,900	21.9
1965	3,430	6,700	27,000	12.7
1985	983	8,210	46,600	2.1
2004	0	12,600	73,700	0.0
Zinc				
1945	694,000	773,000	1,470,000	47.2
1965	902,000	1,230,000	4,310,000	20.9
1985	261,000	961,000	6,760,000	3.9
2004	189,000	1,160,000	9,600,000	2.0

NOTE: Apparent consumption is a calculated figure equal to Production + Imports – Exports +/– (Stock Change). Data are provided for four specific years: 1945, 1965, 1985, and 2004.
SOURCE: USGS (2005), online only: http://minerals.usgs.gov/ds/2005/140/.

RESTRUCTURING IN THE GLOBAL MINERAL SECTOR

The main emerging economies, such as are found in the BRIC countries, are developing their domestic mineral resources to meet both their internal markets and large export markets, with many of their mining companies becoming significant players in the global mineral market in their own right. Another recent trend in the global minerals industry is that with the increasing demand for minerals, Africa, with its geologically rich but largely unexplored areas, is likely to play an increasingly important role in the global minerals market. China's increasing appetite for raw materials and its dearth of domestic resources in certain minerals make it increasingly dependent on raw material imports. To shore up the security of its resource supply lines, Beijing has started to build strategic alliances with countries throughout Africa (Alden, 2005; French, 2007; Large, 2007; Mwega, 2007). In 2005 China overtook the United Kingdom to become Africa's number three trade partner. The United States is number one and France is number two. The $8.1 billion China lent to only three countries (Angola, Mozambique, and Nigeria) in 2006 far exceeded the $2.3 billion contributed in the same period by the World Bank (French, 2007). Its efforts have included building hospitals, schools, roads, and railways in return for access to energy and mineral resources, and as a result China's government-owned companies are locking in exclusive mineral and petroleum rights in Africa. For example, in the Democratic Republic of Congo (DRC), a country with enormous untapped mineral wealth, China is installing concentration facilities to improve the cobalt being shipped.

To make more effective use of the assets already available to the industry and to better scale themselves to world markets, mining companies around the world engaged in a wave of merger and acquisition activity through the late 1990s and early 2000s and sought to use their assets more effectively. They expanded and diversified their operations vertically and horizontally to develop more predictable sales through the economic cycles.[3] The big international metals and mining companies continue to expand and are identifying their targets very precisely, with specific goals to secure and control raw materials and obtain a larger market share. They are obtaining new capacity either by direct acquisition or by capital investment in new facilities (Box 3-1).

The global trends that are only touched on here are causing the mineral market to become more centralized and integrated. There are benefits and risks involved in this consolidation. The major risk of consolidation is that there is an associated risk that fewer players and less competition in the materials market might lead to increased prices. On the benefit side, the large, diversified mineral companies are

[3]See David Humphreys, Corporate Strategies in the Global Mining Industry (2002). Available at http://www.dundee.ac.uk/cepmlp/journal/html/vol12/article12-9.html. Accessed June 2007.

BOX 3-1
Recent Consolidation in the Mining Sector

In 2002 the three largest diversified miners—Rio Tinto, BHP Billiton, and Anglo-American—ccounted for around 30 percent of the market capitalization of the mining sector. This compared with 15 percent in 1990. BHP Billiton is the largest international mining company today, with 38,000 employees working in more than 100 operations in approximately 25 countries. BHP Billiton, with 2006 sales of $39 billion (2002 sales were $17 billion) is the largest supplier of iron ore, the second largest coal exporter, the second largest copper mining company, the third largest nickel miner, the fourth largest uranium miner, and the sixth most important aluminum ore miner.

In 2006, there were a number of significant mining and metal industry mergers and acquisitions. Falconbridge Ltd. and Inco Ltd., which had initially proposed merging, became the objects of multiple takeovers. Swiss-based Xstrata PLC took control of Canadian miner Falconbridge (one of the world's biggest nickel and copper producers). The Brazilian company Companhia Vale do Rio Doce (CVRD), acquired Inco, one of Canada's leading mining companies, for C$ 19 billion. The new company, CVRD-Inco, is now the world's fifth-largest producer of nickel, copper, and iron ore. In addition, the Indian company Tata Steel Ltd. made an offer for Corus Group plc, a much larger European firm. In aluminum, Russian producers RUSAL and SUAL also merged, creating a monopoly on the Russian aluminum market.

The world's largest steel company, Arcelor Mittal, was born when Mittal Steel, led by Indian national Lakshmi Mittal, acquired the European steel company Arcelor (Aston et al., 2004; Reed, 2007). Arcelor Mittal is the first truly international steel company, and it counts among its assets remnants of several legendary U.S. steel companies, including Bethlehem Steel, Inland Steel, LTV, and Weirton Steel. At the end of 2006, U.S. mining company Phelps Dodge, the world's second-largest copper producer, was acquired by fellow U.S. company Freeport-McMoRan Copper & Gold.

stronger and more able to weather the market slumps that would close smaller companies. Their access to capital resources allows them to make major investments in new production capacity in the developing world. They are better able to accept the geopolitical risks of third-world exploration and development. The effects of such consolidation on supply assurance and stockpile strategy are far from clear.

CONCLUSIONS

As described in this chapter, mining and mineral processing are increasingly global enterprises. The emerging economies, including the BRIC countries, are becoming larger consumers of minerals and having more influence on the supply base as well. The worldwide capacity for mining and refining of minerals is increasingly located outside the United States, which itself is increasingly reliant on foreign sources of minerals in their various forms. In the committee's judgment, foreign dependence is not, per se, a cause for concern. But it may become so when combined with political instability in the source regions and greater competition for mineral resources across the globe. The decrease in the U.S. share of world consumption calls into question its historical ability to command supply in times of shortage. As will be explored at more length in Chapter 5, the committee believes that other mitigating actions, such as the possibility of scrap recycling as a source of supply, must be considered.

Historically, the committee's judgment is that NDS policy has been driven by concern over supply interruptions rather than price spikes (indeed, the legislation governing NDS policy disallows the pursuit of economic stabilization objectives). And in the new environment characterized by greater threats from nonstate actors, the risk of supply interruptions has arguably increased. Although supply interruptions almost certainly will trigger price increases, under some circumstances price shocks may not result in expanded supply, particularly within the time horizon relevant for defense planning. The committee believes that stockpile policy should continue to give supply assurance priority over price stabilization when it comes to defense-critical strategic materials.

Although U.S. dependence on imports of many defense-critical strategic materials has increased, it is a necessary but not a sufficient reason for designating a defense-critical material as a candidate for stockpiling. Building on the criteria suggested in the 1975 GAO report, the criteria for including a material in the NDS could now include:

- U.S. dependence on imports,
- Concentration of supplies among a small number of regions or enterprises,
- The potential for political instability in key supplier regions, and
- The lack of substitutes for the defense applications in which the materials are incorporated.

Defense-critical materials that meet all or a significant subset of these criteria have been (or should be) the focus of stockpile policy, and the committee believes that changes in the global economy described above have affected a number of these criteria for a few materials. However, there is little evidence that these changes in the global economic and political environment have influenced stockpile policy and management.

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4

Changing Defense Planning and Defense Materials Needs

According to the legislation governing the National Defense Stockpile (NDS), its purpose is "to provide for the acquisition and retention of stocks of certain strategic and critical materials and to encourage the conservation and development of sources of such materials within the United States and thereby to decrease and to preclude, when possible, a dangerous and costly dependence by the United States upon foreign sources for supplies of such materials in times of national emergency."[1] Strategic and critical materials are defined as "materials that (A) would be needed to supply the military, industrial, and essential civilian needs of the United States during a national emergency and (B) are not found or produced in the United States in sufficient quantities to meet such need."[2] A national emergency is defined as a general declaration of emergency with respect to the national defense made by the President or by the Congress. The NDS legislation specifically states that the stockpile is not to be used for economic stabilization.

Following World War II, the historical context for the NDS mission was a national emergency in which U.S. defense forces were fighting a global war against Soviet aggression. Today the United States faces a very different type of threat, and the military forces have changed markedly in strategy, force structure, equipment, and technology. This chapter discusses changes in the strategic threats and U.S. force planning and describes why the committee believes the NDS has been unable

[1]50 *U.S.C.* 98, Section 2 (b).
[2]50 *U.S.C.* 98, Section 12 (1).

to adapt to them. (A more detailed discussion of the evolution of defense planning is in Appendix B.)

CHANGES IN DEFENSE PLANNING

Significant shifts in defense planning, strategy, and processes have taken place since the end of the Cold War and today's Global War on Terror (GWOT). Beginning with the first Bush administration's Base Force concept in 1989 through today's Transformational Efforts and Capabilities-Based Planning, the Department of Defense (DoD) has steadily adjusted its strategic course and capabilities to address the changed threat and meet the challenges posed by the global security environment.

U.S. defense planning historically has been based on an enumeration of likely war-fighting scenarios. Thus, in the early days of the Cold War, defense planners calculated their risk analyses based on the need to be able to respond to two and one-half conflicts at one time (that is, possible wars with the Soviet Union in Europe and with the People's Republic of China in Asia and a half-war with another regional state, in the event Vietnam). For the most part, successive administrations relied on this basic conflict-counting strategy (Kaplan, 2005). President Nixon's strategy presumed the need to respond to one and one-half conflicts simultaneously, for example. The recent history of defense planning, and the history most pertinent to understanding the NDS and its relevance to defense needs, breaks down into two turning-point periods—1990-2001 and post-9/11.

1990-2001

With the fall of the Berlin Wall came the recognition that U.S. defense planning and force structuring would need fundamental realignment with concentration on addressing regional rather than global conflict while maintaining a minimal force and preserving a hedge capacity to rebuild defenses for global warfare in the event of a resurgent superpower rivalry (Larson et al., 2001). As such, the defense strategy for the 1990s, as outlined in the 1992 National Military Strategy (NMS), called for a new, four-pronged approach based on strategic (nuclear) deterrence and defense, forward presence (that is, a smaller force than conceived under the previous forward defense strategy); crisis response (given the uncertainty surrounding the geographic location of future conflicts); and reconstitution (Powell, 1992).

The last two prongs of the strategy explicitly allowed for a return to Cold-War-era force levels and capabilities if necessary. This was deemed a vital part of the defense strategy given domestic—that is, congressional—interest at the time in cutting defense spending in order to reap a "peace dividend," a goal that Pentagon officials feared might cut too deep into military readiness (Jaffe, 1993). Interestingly, as explained in the NMS, the stockpiling of critical materials was an integral part of this plan:[3]

> Preserving the potential for expansion of air, ground, and maritime forces will require extraordinary foresight and political courage to lay away infrastructure, stockpile critical materials, protect the defense industrial base, sustain a cadre of quality leaders, and invest in basic science and high-payoff technologies. Reconstitution also requires important decisions based on early strategic warning.

and

> A key element in responding to this challenge is Graduated Mobilization Response. This national process integrates actions to increase our emergency preparedness posture in response to warning of crisis. These actions are designed to mitigate the impact of a crisis and to reduce significantly the lead time associated with responding to a full scale national security emergency.

However, before the base force plan of the first Bush administration could be implemented, world events had overtaken the expectations underlying U.S. strategy: The Soviet Union and its influence on Eastern Europe had collapsed, U.S. forces had effected regime change in Panama, and a new front had opened in the Middle East with Saddam Hussein's invasion of Kuwait. This new strategic environment, unforeseen by DoD strategists, was therefore not reflected in the NDS, which by law is mandated to base its analysis on DoD strategy. A new strategic approach was adopted only when the Clinton administration took over.

In response to new global security challenges the Clinton administration conducted a fundamental bottom-up review (BUR). The end result of this review was a strategy for winning two nearly simultaneous major regional conflicts (MRCs)—North Korea and Iraq (Aspin, 1993). While there was no further mention of the need to maintain a reconstituting capability or a stockpile, the BUR, like its predecessor, contained an explicit hedge approach:

> . . . sizing our forces for two major regional conflicts provides a hedge against the possibility that a future adversary might one day confront us with a larger-than-expected threat, and then turn out, through doctrinal or technological innovation, to be more capable than we expect, or enlist the assistance of other nations to form a coalition against our interests.[4]

Broad dissatisfaction with the two-MRC construct led to a fresh review of U.S. defense strategy and posture 4 years later. The 1997 quadrennial defense review (QDR) adopted a longer-term outlook, assessing security and defense needs through 2015. The result was a strategy designed to "shape the international security environment in ways favorable to U.S. interests, respond to the full spectrum of crises when directed, and prepare now to meet the challenges of an uncertain future" (DOD, 1997). Nonetheless, the force structure outlined to achieve these

[3]NMS (Powell, 1992), pp. 7-8 and 24-25.
[4]See http://www.fas.org/man/docs/bur/part02.htm. Accessed November 2007.

aims was familiar, with the two MRCs renamed major theater wars (MTWs) in overlapping time frames. Added to the two-MTW strategy was the need also to respond to smaller scale contingencies that might arise (as did Bosnia and Kosovo). Additionally, building on the BUR's support for enhanced allied assistance and supply, DoD continued to expand its case for a national defense industrial base with the ability to trade and resource globally as an essential element of long-term U.S. national security.[5] This new, more global approach, however, was not formally reflected in the legislation governing the NDS. Rather, DoD adopted a more expansive view of the clause in the Strategic and Critical Stock Piling Act that reads "a dangerous and costly dependence by the United States upon foreign sources for supplies" to allow global sourcing, given changing world economic dynamics. It appears that DoD and congressional views of how the NDS should operate have diverged over time, with the Pentagon focused on trading globally in order to stay far ahead economically, technologically, and militarily of any and all future competitors, while legislators tended to emphasize a reliance on domestic supply (for example, the Buy American Act and the Berry Amendment).

A review of NDS reports to Congress from the 1990s (detailed in Chapter 6) shows that long periods of time elapsed between changes in the DoD strategy scenarios and the ensuing stockpile recommendations (Table 4-1).

Post-9/11 Period

Another key turning point in defense strategy and resource planning was the *2001 Quadrennial Defense Review* (QDR). Following the terrorist attacks of 9/11, the first version of the *2001 QDR*, which came out shortly thereafter, had to be hastily revised to further emphasize homeland defense (Box 4-1). The main innovation stemming from this review was the adoption of a capabilities-based approach in place of the traditional threat-based strategy. In other words, rather than focus on trying to anticipate and identify probable future threats (that is, state or nonstate actors), the capabilities-based approach is designed to assure a force structure ready to meet any potential threat regardless of its origin, geography, or timing. The defense strategy outlined in the *2001 QDR* therefore took a four-pronged approach to dealing with a range of concerns, threats, and possible conflicts. As this new force-planning structure evolved, it would come to be known as the 1-4-2-1 strategy:

[5]For a comprehensive argument outlining DoD's interests in supporting a dual-use, globally sourced defense industrial base, see DSB (1999).

TABLE 4-1 Comparison of Changes in DoD Strategy, the Approach to Stockpiling (if Any), the Impact on the Assumptions Made in the Stockpile Requirements Analysis, and the Number of Requirements Reported to Congress

	DoD Strategy		DoD Stockpile Reports to Congress	
	Elements	Stockpile Approach	Stockpile Assumptions	Number of Reported Stockpile Requirements
Base Force (1989-1992)	Strategic deterrence and defense Forward presence Crisis response Reconstitution	Reconstitution included as an explicit part of strategy to hedge against potential resurgence of Soviet Union	Indefinite duration conflict Requirements modeled for first 3 years 1-year warning time (1989-1991) 3-year mobilization (1993-) after nonnuclear, conventional conflict	1989: 48 requirements reported 1992: 20 requirements reported
Bottom-Up Review (1993-1997)	2 MRCs Prepositioning of military supplies overseas	Not addressed	7-9 years warning (1995-) 2-4 years mobilization 3-year conflict (3-4 months intense; 2 years+ stalemate; 3-4 months wrap-up)	1993: 7 requirements reported 1995: 3 requirements reported
QDR (1997-2001)	2 MTWs	Not addressed	Little warning 1-year conflict (1999-) 3-year regeneration period	1997: 6 requirements reported 1999: 3 requirements reported
2001 QDR (2001-2005)	1-Defend the homeland 4-Deter forward in 4 critical regions 2-Swiftly defeat 2 adversaries nearly simultaneously 1-Win 1 decisively	Not addressed	Little warning 1-year conflict (1999-) 3-year regeneration period Catastrophic U.S. incident added	2001: 4 requirements reported 2003: 3 requirements reported 2005: 3 requirements reported

continued

TABLE 4-1 Continued

	DoD Strategy		DoD Stockpile Reports to Congress	
	Elements	Stockpile Approach	Stockpile Assumptions	Number of Reported Stockpile Requirements
2006 QDR (2006-2010)	1-Defend the homeland 4-Respond to the spectrum of conflict 2-Swiftly defeat 2 adversaries nearly simultaneously 1-Win 1 decisively Prepositioned stocks Stockpile routine defense articles such as helmets, body armor, and night vision devices for use by coalition partners	Not addressed		

NOTE: The table shows NDS assumptions significantly lag changes in DoD strategy and that requirements have been reduced to near zero. Table 6-4 gives more details on the requirements reported.

1 Defend the United States,
4 Deter forward in 4 critical regions (Europe, northeast Asia, east Asian littoral, southwest Asia),
2 Swiftly defeat two adversaries nearly simultaneously, and
1 Win one decisively—that is, potential regime change.[6]

The strategy also maintained the need to be able to respond to small-scale contingencies but added a "force generation capacity" and a strategic forces reserve. This is the defense planning strategy that currently underlies the most recent IDA analysis for the NDS.

The latest iteration of defense planning as outlined in the most recent *2006*

[6]The 1-4-2-1 construct is formally referenced in the 2004 National Military Strategy (Myers, 2005), a product of the Chairman of the Joint Chiefs of Staff in support of the National Security Strategy (a White House document) and implementing the 2005 National Defense Strategy (from OSD). IDA's analysis adds a "1" to the 1-4-2-1 construct: one smaller scale contingency. The 2005 National Defense Strategy, however, states the need to also conduct a limited number of lesser contingencies (Rumsfeld, 2005).

BOX 4-1
Homeland Defense

As described in the National Strategy for Homeland Security (Office of Homeland Security, 2002), the strategic objectives of homeland security in order of priority are to "prevent terrorist attacks within the United States; reduce America's vulnerability to terrorism; and minimize the damage and recover from attacks that do occur."[a]

Recovery includes the full range of efforts to build and maintain various financial, legal, and social systems to recover from all forms of terrorism. The United States must be prepared to protect and restore institutions needed to sustain economic growth and confidence, rebuild destroyed property, assist victims and their families, heal psychological wounds, and demonstrate compassion, recognizing that we cannot automatically return to the preattack norm.

The strategy aligns and focuses homeland security functions into six critical mission areas: intelligence and warning, border and transportation security, domestic counterterrorism, protecting critical infrastructure, defending against catastrophic terrorism, and emergency preparedness and response. The first three mission areas focus on preventing terrorist attacks (the first strategic objective); the next two on reducing the nation's vulnerabilities (the second); and the final one on minimizing the damage and recovering from attacks that do occur (the third). The U.S. military has ongoing and emergency roles in each of these mission areas. DoD contributes to homeland security through its military missions overseas, homeland defense, and support to civil authorities.

There are three circumstances under which DoD could be involved in improving security at home. In extraordinary circumstances and coordinated, as appropriate, with the National Security Council, the Homeland Security Council, and other federal agencies, it could carry out domestic military missions such as combat air patrols or maritime defense. Second, DoD could be involved during emergencies by, for example, responding to an attack or to forest fires, floods, tornadoes, or other catastrophes, providing capabilities that other agencies do not have. It could also take part in limited-scope missions where other agencies have the lead—for example, security at a special sporting event. Third, in response planning, DoD has responsibility for the infrastructure protection plan, vulnerability assessment, and threat warning for the defense industrial base.

These specific homeland security missions may have an impact on the NDS in the following areas:

- Major military operations in the United States requiring a surge of logistics support, such as wide-area infrastructure protection or extensive disaster relief.
- Disruption (by physical attack, natural disaster, pandemic illness) of vulnerable critical supply nodes, such as a mineral processing plant, a transportation center, or a consolidated supply depot that would impact military logistics.

[a]Office of Homeland Security, 2002. p. viii.

QDR (DoD, 2006) is a modified 1-4-2-1 approach, where the "4" now refers to the need to respond to a spectrum of challenges that are irregular, traditional, catastrophic, or disruptive, as depicted in Figure 4-1.[7] The *2006 QDR* expands on the fundamental strategy set out in the 2005 National Defense Strategy, the source of the new quadrangular approach to dealing with old and new security challenges. The 2005 strategy also outlines "four guidelines [that] structure our strategic planning and decision-making." These are an active, layered defense; continuous transformation; a capabilities-based approach; and managing risks (Rumsfeld, 2005). The *2006 QDR* also assumes both a steady-state and a surge force capacity, but unlike the earlier Base Force strategy, it does not discuss the need for a materials stockpile for these purposes.

Stockpile Implications of a Transformed Military

The evolving defense scenarios outlined above have had significant impact on the kinds of defense systems required by the military and, by extension, the materials needs of the services and the stockpiling of the most critical of those materials. Considering the *2006 QDR*, discussed in the preceding section, the traditional (nation-state adversaries) challenge is the most conventional threat that the stockpile is meant to address, because it assumes a straightforward, predictable buildup of forces and a definable operational campaign. The other challenges (irregular, catastrophic, disruptive) are much more unpredictable in terms of impact and response time. Our adversaries may attack vulnerable nodes and links in our military supply chain and disrupt our operational effectiveness and sustainability. These new challenges need to be reflected in future stockpile analysis as part of the materials supply chain.

In addition, the *2006 QDR* outlines a number key differences in DoD strategy under the aegis of transformation. A few differences that might impact a future stockpiling activity include the following changes to the force structure (DoD, 2006, pp. vi-vii):

- From a peacetime tempo – to a wartime sense of urgency.
- From responding after a crisis starts (reactive) – to preventive actions so problems do not become crises (proactive).
- From a time of reasonable predictability – to an era of surprise and uncertainty.
- From peacetime planning – to rapid adaptive planning.
- From static defense, garrison forces – to mobile, expeditionary operations.

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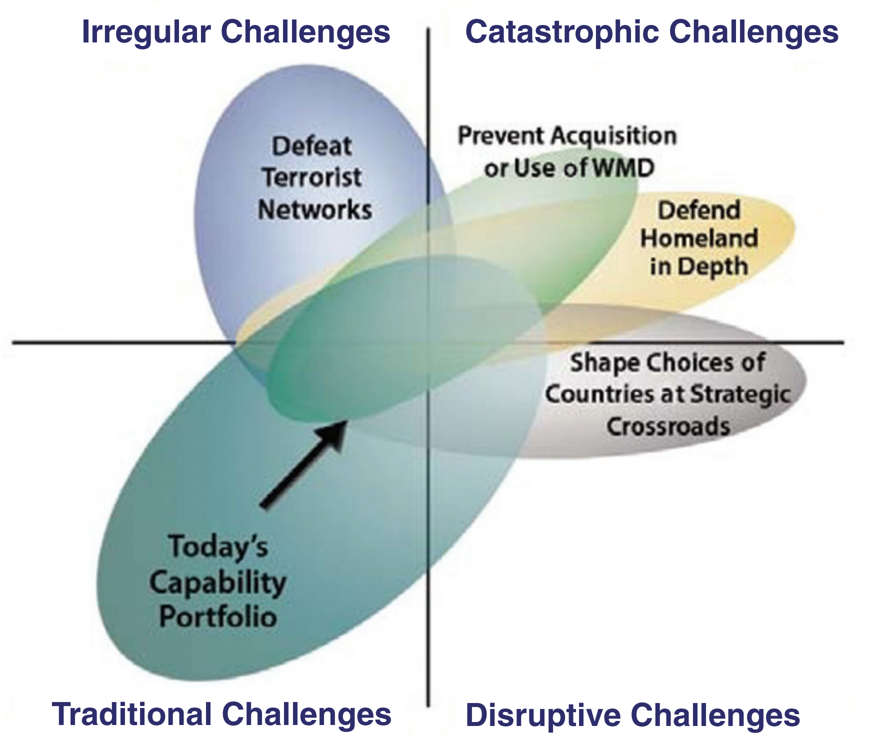
[7]The 1-4-2-1 construct does not appear in the QDR document. However, as in the earlier QDR process, Pentagon officials use this shorthand in describing the present strategy. For the formal document (which was due in 2005 but was delayed), see Office of the Secretary of Defense, *2006 Quadrennial Defense Review* (DoD, 2006).



Irregular	**Catastrophic**
Nonstate and state actors employing unconventional methods to counter stronger state opponents (*erode* our power) Examples: terrorism, insurgency, civil war, and emerging concepts like unrestricted warfare *Likelihood*: very high; strategy of the weak	Terrorist or rogue state employment of WMD or methods producing WMD-like effects against American interests (*paralyze* our power) Examples: attack on homeland, global markets, or key ally that would generate a state of shock and preclude normal behavior *Likelihood*: moderate and increasing
Traditional	**Disruptive**
States employing military forces in well-known forms of military competition and conflict (*challenge* our power) Examples: conventional air, sea, and land forces and nuclear forces of established nuclear powers *Likelihood*: currently decreasing due to historic capability overmatch and expanding qualitative lead	Competitors employing technology or methods that might counter or cancel our current military advantages (*capsize* our power) Examples: technological—bio, cyber, or space war, ultraminiaturization, directed-energy, other—diplomatic blackmail, cultural or economic war *Likelihood*: low, but time works against the United States

FIGURE 4-1 *Top*: QDR responses to the spectrum of challenges. SOURCE: *2006 QDR*, p. 19. *Bottom*: Types of challenges in the QDR strategic environment. SOURCE: Henry (2006).

- From separate military Service concepts of operation – to joint and combined [international] operations.
- From exposed forces forward – to reaching back to the continental United States to support expeditionary forces.
- From broad-based industrial mobilization – to targeted commercial solutions.
- From vertical structures and processes (stovepipes) – to more transparent, horizontal integration (matrix).
- From the U.S. military performing tasks – to a focus on building partner capabilities.

The committee believes that the current NDS approach is unable to effectively adapt to these trends.

An important change in military planning in recent years that is relevant to the concept of a materials stockpile is that the idea of reconstituting (and mobilizing the domestic industrial base). This activity is no longer mentioned in the current strategy documents. Rather, it is taken for granted in DoD that needed supplies can be acquired from the global marketplace in sufficient quantity and in time. However, this approach is at odds with the NDS approach as originally mandated by Congress.

The fact is that the NDS and its supporting legislation remain focused on an outdated, low-probability mission of national mobilization and reconstitution. The pressing requirement is to support a transforming military that is conducting expeditionary operations against changing threats around the world without the benefit of national mobilization. The committee believes that the NDS mission of supporting national mobilization and reconstitution is disconnected from current national defense strategies and operational priorities.

DEFINING TWENTY-FIRST CENTURY DEFENSE MATERIALS NEEDS

Military (land, sea, and air) combat and support systems have seldom been static in terms of technology. The quantity and type of materials needed to support military systems continue to change dynamically with the introduction of new systems—such as Stryker Brigades, Littoral Combat Ships, converted cruise-missile-firing submarines, unmanned vehicles, and advanced tactical aircraft—and upgrades of fielded systems. All of these different systems are linked by so-called “net-centric” warfare networks, which are highly dependent on rapidly evolving computer, information, and communication technology.

Looking beyond immediate needs, the future systems of the twenty-first century military will also need to demonstrate multifuctionality, self-diagnosis and self-healing, low cost, low maintenance, environmental acceptability, and high reliability. Some trends in warfare can be expected to continue: The need will increase for a precision strike force that can maneuver rapidly and effectively and survive an attack, all while distant from its command post and base. In addition, the force must be able to conceal its activities from an enemy while detecting enemy activities. Advances in information technology will increase coordination among forces, and global awareness—through real-time networked sensors and communications—will facilitate command and control and enable precision strikes. With the use of unmanned vehicles, military power will be delivered remotely and casualties will be reduced. Fighting in urban areas will increase, requiring entirely different strategies and equipment, and guerilla warfare will require new strategies and weapons.

A comprehensive, service-by-service assessment of current and future defense materials needs was beyond the scope and the time and resources available to the committee. However a number of studies over the last 5 years have considered how new threats, new adversaries, and emerging disruptive technologies have led to new challenges to which the nation and, specifically, the Departments of Defense and Homeland Security must respond. For summaries of a number of key reports, see Appendix C. The needs identified below are based on the conclusions of those reports.

Meeting the Materials Needs for Today's Rapidly Changing Military Technology

The production and supply of many if not most of the advanced materials that the military will continue to deploy into the twenty-first century will depend on minerals such as those for which the United States is already highly import-dependent. These materials are many and varied. Even ubiquitous technologies, such as those found in computer systems, are reliant on materials and minerals that are high on the USGS import reliance list (Table 4-2).

It was not possible as part of the current study to do a comprehensive assessment of materials needs, current or future, or to fully digest the various critical materials definitions, including the DoD's Military Critical Technologies List (MCTL). As an example, the committee asked the chapter chairs from the committee that wrote *Materials Research to Meet 21st Century Defense Needs* (NRC, 2003) two questions: (1) Have there been any major changes in the R&D environment or defense needs that would affect that report's outcomes if they were revisited today? and (2) What are the critical raw materials that are crucial to the materials identified in that report which if their supply was disrupted would pose a significant risk to national security? In response, the chapter chairs uniformly said that the materials R&D directions foreseen in the 2003 report are still largely correct. They also identified some minerals and materials as being important for specific applications (both directly and indirectly defense related). These inputs, along with the committee's own expertise in materials and defense needs as well as inputs from some published sources, are summarized in Table 4-3. The table also shows the import reliance data for these materials in 2006 where available.

TABLE 4-2 Minerals in a Typical Computer System

Computer Component	Element or Compound Used	Mineral Source of Element
CRT monitor, phosphorescent coating, transition metal	Zn, S	Sulfur, hemimorphite, zincite, smithsonite, franklinite
	Ag	Silver, pyrargyrite, cerargyrite
	Cl	Halite
	Al	Bauxite
	Cu	Chalcopyrite, boronite, enargite, cuprite, malachite, azurite, chrysocolla, chalcocite
	Au	Gold
	Y	Euxenite
	Eu	Euxenite
	K, F, Mg, Mn	Alunite, orthoclase, nephelite, leucite, apophullite; Fluorite, cryolite, vesuvianite, lepidolite, dolomite, magnesite, espomite, spinel, olivine, pyrope, biotite, talc, pyroxenes
	Cd	Greenockite
	As	Realgar, orpiment, niccolite, cobalite, arsenopyrite, tetrahedrite
	Gd, Tb	Monazite, bastnäsite. cerite, gadolinite, monazite, xenotime, euxenite
	Ce	Monzanite, orthite
CRT monitor glass	Pb	Galena, cerussite, anglesite, pyromorphite
	Si	Quartz
Plastic case, keyboard	Ca	Calcite, gypsum, apatite, aragonite
	Ti	Rutile, ilmenite, titanite
	P	Apetite, pyromorphite, wavellite
Liquid crystal display (LCD) monitors	Pb	Galena, cerussite, anglesite, pyromorphite
	Si	Quartz
	Fe	Hematite
	Sn	Cassiterite
	In	Sphalerite (commonly found with zinc)
Metal case	Fe	Magnetite, limonite

TABLE 4-2 Continued

Computer Component	Element or Compound Used	Mineral Source of Element
Flat-screen plasma display monitors	Si	Quartz
	Pb	Galena, cerussite, anglesite, pyromorphite
	Zn, S	Sulfur, hemimorphite, zincite, smithsonite, franklinite
	Ag	Silver, pyrargyrite, cerargyrite
	Cl	Halite
	Al	Bauxite
	Cu	Chalcopyrite, boronite, enargite, cuprite, malachite, azurite, chrysocolla, chalcocite
	Au	Gold
	Y	Euxenite
	Eu	Euxenite
	K, F, Mg, Mn	Alunite, orthoclase, nephelite, leucite, apophullite; fluorite, cryolite, vesuvianite, lepidolite, dolomite, magnesite, espomite, spinel, olivine, pyrope, biotite, talc, pyroxenes
	Cd	Greenockite
	As	Realgar, orpiment, niccolite, cobalite, arsenopyrite, tetrahedrite
	Gd, Tb	Monazite, bastnäsite. cerite, gadolinite, monazite, xenotime, euxenite
	Ce	Monzanite, orthite
Printed circuit boards, computer chips	Si	Quartz
	Cu	Chalcopyrite, boronite, enargite, cuprite, malachite, azurite, chrysocolla, chalcocite
	Au	Gold
	Ag	Silver, pyrargyrite, cerargyrite
	Sn	Cassiterite,
	Al	Bauxite

NOTE: The list shows 66 individual minerals that contribute to the typical computer. This list does not purport to be complete but is presented to show the reader that there are many many minerals involved in the manufacture of a commonplace everyday good such as the computer or, indeed, the television. The path connecting the mineral to the finished good can be long and indirect, and in practice, many of these minerals pass through one or more phases in which they are converted into complex organometallic compounds or inorganic gas precursors before being used in the manufacture of the components listed. Also there are other materials in addition to those listed here. All that notwithstanding, it should be evident from this table that the manufacture of such commonplace items as computers and televisions is dependent on the availability of a wide range of minerals.
SOURCE: http://mine-engineer.com.

TABLE 4-3 Uses of Selected Strategic and Critical Materials and Import Reliance (Where Available)

Material/Metal	Uses	Net Import Reliance (%)
Aluminum	Aluminum alloys in airplanes, aerospace, marine applications, food cans	44
Arsenic	Semiconductors, pyrotechnics, insecticides	100
Beryllium	Military optics and guidance systems	E[a]
Bismuth	Magnets, nuclear reactors, thermoelectrics, ceramic glazes	96
Cerium	Catalytic converter substrates	NA[b]
Chrome	Specialty steels	NA
Chromium	Steels, catalysts, magnetic tape, plating	75
Cobalt	Specialty steels; medium- or high-temperature fuel cells	81
Columbium	Specialty steels	100
Copper	Wire, electromagnets, circuit boards, switches, magnetrons	40
Europium and others	Display phosphors	NA
Gadolinium	Magnetic refrigeration	NA
Gallium	Optoelectronics, integrated circuits, dopant, photovoltaics	99
Indium	Semiconductors, metal organics, light-emitting diodes	100
Lanthanum	Catalytic converter substrates	NA
Lithium	Batteries	>50
Magnesium	Airplanes, missiles, autos, photography, pharmaceuticals	54
Manganese	Specialty steels	100
Molybdenum	Specialty steels	E
Neodymium	High-strength magnets; laser dopant	NA
Nickel	Specialty steels; superalloys for jet engine parts	60
Platinum	Catalytic converters—reduction of carbon monoxide and hydrocarbons	80[c]
Quartz crystals (high purity)	Electronic and photonic devices	100
Rhenium	Specialty steels; high-temperature alloys and coatings	87
Rhodium	Reduction of oxides of nitrogen in catalytic converters	NA
Samarium	High-strength magnets	NA
Scandium	Refractory ceramics, aluminum alloys	100
Selenium	Photovoltaics, solar cells, rectifiers, surge protectors, xeroradiography	NA
Silicon	Photovoltaics, semiconductors, microprocessors, alloys, electronic and photonic devices.	<50
Strontium	Medium- or high-temperature fuel cells	100
Tantalum	Specialty steels; electronic capacitors	87
Tin	Superconducting magnets, solder, alloys, electronic circuits	79
Titanium mineral concentrates	Alloys: jet engine compressor components; aircraft structural members; medical devices; power generation equipment; chemical and petrochemical refining and manufacture; and oil and gas extraction and recovery	NA

TABLE 4-3 Continued

Material/Metal	Uses	Net Import Reliance (%)
Tungsten	Specialty steels	71
Yttrium	Laser rods, superalloys	100
Zinc	Batteries, galvanizing, paints, metal organics, pharmaceuticals	63

[a]E, net exporter.
[b]NA, not available.
[c]Data for platinum group metals (platinum, rhodium, ruthenium, iridium, and osmium).
SOURCE: Based on data from the committee analysis and the following: Gassner (2007); Herring (2007); Lipsitt (2007); Marder (2007); Pfahl (2007); Phillips (2007); Sloter (2007). Import reliance data from USGS (2007).

Emerging and Future Materials Needs

Turning to future defense systems, it is expected that these would employ advanced materials that are self-healing, that can interact independently with the local environment, and that can monitor the health of a structure or component during operation (DSB, 2002). Some advanced materials could serve as hosts for embedded sensors and integrated antennas. Others could deliver high performance in structures by protecting against corrosion, fouling, erosion, and fire; controlling fractures; and serving as fuels, lubricants, and hydraulic fluids. The next 20 years will present the materials community with daunting challenges and opportunities. Material producibility, cost, and availability requirements will be much more demanding than they are today. On the other hand, spurred by the rapid pace of advances in electronics and computation, the performance, life span, and maintainability of materials will be greatly enhanced.

Some high-priority military areas where it has been recommended that DoD focus its activities are defending against biological warfare; finding and correctly identifying difficult targets; supporting high-risk operations with systems capable of high-risk tactical operations; missile defense; affordable precision munitions that are resilient to countermeasures; enhanced human performance; rapid deployment and employment of forces globally against responsive threats; and the rapid delivery, anywhere, of "global effects." In addition, the continuing stewardship of the U.S. strategic nuclear arsenal and efforts to counteract the proliferation of nuclear materials across the globe remain a national security priority of the highest order.

Also, since September 11, 2001, there has been a refocusing of the nation's attention, to national and homeland security. The highest priority is given to developing and utilizing robust systems for protecting, controlling, and accounting for nuclear weapons and special nuclear materials at their sources; ensuring the production and distribution of treatments and preventatives for pathogens; designing, testing, and installing coherent, layered security systems for all transportation modes; protecting energy distribution services; reducing the vulnerability of ventilation systems and improving the effectiveness of air filtration in them; deploying technologies and standards that would allow emergency responders to reliably communicate with one another; and ensuring that trusted spokespersons will be able to inform the public promptly and with technical authority whenever the technical aspects of an emergency dominate the public's concerns (NRC, 2002).

Meeting the defense needs of the country in the twenty-first century will rely on R&D in materials and processes to improve existing materials and achieve breakthroughs in new materials and combinations. According to a recent report (NRC, 2003), some of the materials needed are these:

- Lightweight materials that provide functionality equivalent to that of their heavier analogues;
- Materials that enhance protection and survivability;
- Stealth materials;
- Electronic and photonic materials for high-speed communications;
- Sensor and actuator materials;
- High-energy-density materials; and
- Materials that improve propulsion technology.

Any consideration of a future stockpile must also be forward-looking, taking into account what new kinds of technologies are likely to be entering the market. The committee thought about these issues carefully, and—based on the above assessments of current and future needs, presentations by outside experts, and the committee's own experience of materials and defense needs—came up with a list of materials and technologies that could have a conspicuous impact on defense capabilities.

The committee stresses that this list is speculative. It does not wish to imply that all, or indeed any, of these materials are the most critical ones now or ever. But with the rapid pace of current research, some of them may be available to defense systems manufacturers in the not too distant future and may turn out to be important to defense systems.

The materials mentioned below, or indeed anywhere in this chapter or report, are not discussed with the intent that they necessarily be considered for inclusion in a stockpile, nor are these issues and topics discussed in any specific priority order. They are meant purely to illustrate the diverse and complex web of technologies and materials on which defense systems may depend.

- *Fuel cells* are likely to be an important energy technology in future military systems. Some of the materials on the USGS import reliance list (Figure 3-4) are used as catalysts in fuel cells; some of them are platinum-based. Others, such as strontium and cobalt, are used as key materials in medium- or high-temperature fuel cells. Because fuel cells are one potential solution to the energy problem and will likely become of greater importance in future years, in the ideal case the United States would not depend on foreign sources for the materials used in them. In practice, criticality would likely depend on which technologies are the most fruitful and on the demand for fuel cells employing those particular technologies.
- *Information technology applications* are critically dependent on silicon, gallium (99 percent of which is imported from China, Japan, Ukraine, or Russia), indium (100 percent imported from China, Canada, Japan, or Russia), and arsenic (100 percent from China, Morocco, Mexico, or Chile). Others materials are important but much less so. The imported materials are the backbone of optoelectronics and solid-state photonic materials, with no other technology competing seriously for this market.
- *Tantalum* is important for electronic capacitors. Its main sources are Australia and Africa.
- *The metals critical for turbine engines* (shown with import reliance data from the USGS) are these: nickel, 60 percent; tungsten, 66 percent; chromium, 75 percent; cobalt, 81 percent; tantalum, 87 percent; and rhenium, 87 percent. The two most important alloying elements for aluminum alloys are magnesium, 54 percent, and silicon, 60 percent.
- *Organic low and high molecular weight compounds* are synthesized from basic chemical building blocks whose supply is not vulnerable. However, the situation is more complex and the supply more prone to vulnerability for functional organic materials containing covalently bonded metals. The synthetic routes of production very often require metal-containing catalysts. It is anticipated that hybrid organic-inorganic devices will be a focus of development, raising the same material availability issues that pertain to conventional semiconductor technologies (Karasz, 2007). Overall, a wide range of metals is in play with these organics; although often used in very small amounts, they are important. While it would be speculative to provide a comprehensive list of the metals that might be required, many transition and rare earth metals would be among them, including many of the metals on the USGS list.
- *Activated materials* based on pellet-type media that use activated carbon and sodium permanganate-impregnated alumina are being developed by one company with the U.S. Army Corps of Engineers to develop products that permanently eradicate odorous, corrosive, toxic, and hazardous gases

from airstreams by chemisorption (Jones, 2007). These materials are currently used in several commercial applications but could one day prove to be important for homeland defense needs.

- *Nanotechnology*, the engineering of functional systems at the molecular or atomic scale, has the potential to affect the manufacture of a wide range of materials and products, including pharmaceuticals, catalysts and other chemicals, aerospace materials, materials for health care applications, electronic materials, and so on. The materials required for nanotechnology as it is applied in defense systems will grow in criticality.
- *Smart structures and materials* are materials that can sense external stimuli and can be designed to respond in real or near-real time. They could be used in sensing systems, vibration control, actuators, self-repairing structures, artificial sphincters (Luo et al., 2003), and smart variable resistance devices using magnetorheological fluid dampers (Dong et al., 2006).
- *Biomimetics* is the study of the structure and functioning of biological substances as models for the design of materials and manufacturing. The potential of biomimetics for sensor platforms (in defense), drug delivery systems (health care), autonomous biorobots (space exploration), and other applications appears great.
- *Microelectromechanical systems* (MEMS) are made by integrating a diverse family of complementary technologies such as sensors, actuators, mechanical structures, and electronics into a system that can sense mechanical, thermal, chemical, biological, optical, and magnetic measurements on the micron scale.
- *The supply of low-end electronic parts* now comes almost entirely from foreign countries (Phillips, 2007). Even though these devices are relatively unsophisticated, they are not readily reverse engineered. Hence there is no guarantee against what might be termed “Trojan” components that could compromise an important defense system. Also, there could be concern about the reliability of supply of the front-end or raw materials/minerals that serve the manufacturing processes, and that concern might motivate the United States to hold a reserve of such materials.
- *Tellurium* may become significant in the near future. It is used in chalcogenide glasses for missile nose cones and to focus infrared light. It is used to alloy with steels or copper in ceramics and blasting caps to make them more workable. Organic tellurides are antioxidants. Bismuth telluride is used in thermoelectric devices, cadmium telluride may be used in solar panels, and zinc telluride is used in solid-state x-ray detectors.
- *Rare earth element* (REE) metals have good magnetic, thermal, and electrical properties and are widely used in weapons and other military applications. REEs are used in electronics, communications, optics, catalysts,

and petroleum refining. Sometimes yttrium, scandium, and thorium are included with REEs. Appendix D describes REEs in more detail.

- *Rare metals* are produced, in general, as by-products during the extraction of other metals, so if those other metals are no longer mined, for whatever economic or environmental reasons, these valuable by-products are also lost. For example, rhenium (Re) is a by-product of molybdenum roasting and is used in very high temperature nickel-base alloys for jet engines.
- *Composites* have great strength and a high stiffness-to-weight ratio and are becoming more important in airplanes and lighter, mobile applications. Because of how they are made, they are readily adapted to the embedment of sensors, actuators, and the like. Composites will probably become even more important with the advent of nanotechnology, the development of improved self-healing properties, and the development of future wireless equipment (NRC, 2003).
- *Advanced ceramics* are being used more often in lightweight body armor, infrared missile domes, coatings for aircraft engine components, and space applications. The efforts to reduce the costs of using advanced ceramics in defense systems are likely to result in their greater use.
- *Powder metallurgy* and the use of particulate materials allow molding parts at relatively modest temperatures and in shapes that are close to those final shape of the finished product, markedly reducing the amount of wastage during milling. The use of these materials makes parts more cost effective while maintaining durability, corrosion resistance, and life cycle. Both the automotive and military industries will benefit from these developments.

In 1937, when the stockpile was established, the United States only had to be concerned about maintaining a supply of raw materials since it had the technology to process and manufacture any engineered material or product as long as the raw materials were available. Today, the United States also has to be concerned about whether it has the capacity to produce or obtain sophisticated engineered materials.

CONCLUSIONS

The global security environment, the U.S. national defense strategy, the structure and operation of the U.S. military, and its material and technology requirements have all changed markedly since the end of the Cold War when the NDS was at the height of its operation. The most critical contextual changes are these:

- The United States faces a volatile, complex, global environment as terrorism, weapons of mass destruction, failed states, and near-peer competitors threaten its security at home and abroad across the full spectrum of attack modes.

- A smaller U.S. military is operating at a higher wartime tempo around the globe while transforming itself into a responsive, flexible expeditionary force.
- The material needs of the military are changing in scale, form, and content as the military forces are transformed into smaller, flexible, responsive force packages. New technology is an essential part of military transformation, as advanced systems must be fielded with short development times. These new technologies are dependent on a broad range of high-technology materials that are sourced from around the globe.
- While defense strategy and resource planning have been adjusted to take into account the changing global political and economic environment, the role the NDS plays in this strategy and in DoD's added mission—homeland defense—is unclear. NDS is not configured to be responsive to the current, pressing logistical needs of the military, where new military systems are dependent on very different materials and where surge requirements for high-priority systems may be unmet because of shortfalls in materials and industrial feedstock.

The inability of the NDS to adapt to these contextual changes is manifested in, first, serious time lags between the time U.S. defense strategy is evolved and the time when any associated updating of NDS analysis is attempted and, second, a policy disconnect between DoD force planning becoming a capability-based process and the obsolete analytical methods used to specify materials requirements for the NDS. The conflicting views on the advisability of global sourcing held by legislators and by DoD policy makers exacerbate these disconnects.

The committee concludes that the NDS

- Is not capable, given its current legislative mandate and approach, of meeting the pressing needs of the U.S. military as it operates in today's volatile environment.
- Has not been responsive to changing material requirements as new technology options are introduced into military systems.
- Appears not to be integrated into the force structure planning of DoD.

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5

Managing Today's Materials Supply Chains

Military planning scenarios indicate that the dominant security threat is no longer limited to global war demanding national mobilization and the rationing of strategic materials. Instead the U.S. military must also be ready for limited campaigns around the globe. These campaigns are likely to be involve a rapid response by expeditionary military forces that are flexible and can be tailored to different threats across the full spectrum of conflict types. Responses will be characterized by actions around the world carried out by joint, tailored forces engaging multiple asymmetric and irregular threats at a limited scale over durations that may be short (months) or long (years). The rapid development, supply, integration, and application of new technology and materials in weapons and information systems will continue to be important to success. The Department of Defense (DoD) materials management capability needs to be capable of keeping pace with these changes.

EVOLUTION OF MILITARY PROCUREMENT

The U.S. military services have long been concerned with securing access to technology, resources, and weapons essential to victory in a potential conflict with a capable adversary. While the military's own internal arsenals were originally charged with both designing and manufacturing weapons for the military, since the 19th century the U.S. defense industrial base has consisted of a mix of public and private enterprise. The arsenals typically subcontracted some or all manufacture of the weapons systems and the parts for them to the private sector, particularly in time of war. At the same time the U.S. Army invested substantial resources in developing the technology required to mass produce firearms with interchangeable parts. This effort ultimately played an important role in the development of the American system of manufactures (Hounshell, 1984; Mowery et al., 1998), which fostered the growth of machine tools and trained machinists in the United States and ultimately propelled U.S. manufacturing technology to the fore in the global competition taking place in a variety of commercial industries. In the late 1800s, the U.S. Navy worked closely with the U.S. steel industry to secure access to foreign know-how in high-performance steel, needed to make advanced armor plating for American warships, and underwrote the development of U.S. steelmakers' capabilities in high-quality steels.

During World War I, the Army acted to create an American aircraft industry virtually overnight, where previously there had been none. After the war, the military experimented with a variety of ways to procure successive generations of cutting-edge aircraft as the technology evolved. These experiments ultimately led to the modern U.S. system for procuring high-tech weapons systems. Also during that same war, the Navy had become concerned with the security of the long-distance radio communications that had become essential to command and control in naval warfare. In the 1920s, accordingly, it stepped in to create a pool for all major American radio patents and formed the industrial giant RCA to guarantee that cutting-edge radio technology would remain in U.S. hands.

World War II, for the first time perhaps, was a war that was ultimately won by disruptive advances in technology—the first electronic digital computers, radar, and nuclear weapons, among others. The entire scientific enterprise in the United States—in universities, in industries, in research laboratories—was mobilized and harnessed to the war effort. U.S. industrial capabilities were also integrated into the effort—IBM production lines were converted from office equipment to machine guns, Ford manufactured bombers, and Kaiser turned out cargo ships. Total war meant total industrial mobilization, and that lesson was carried to the Cold War that followed.

The lessons of wartime mobilization learned during the first half of the twentieth century were honed in the 1950s and 1960s into the modern American system of weapons acquisition. The military services were reorganized into the modern Department of Defense, with a civilian control structure established over all aspects of national security. Civilian control was also firmly asserted over the procurement of major weapons systems during this epoch, and in the early 1960s, under corporate management expert Robert McNamara, the modern mechanisms of long-range planning and budgetary programming were firmly embedded in the culture of the Pentagon, where they continue to hold sway.

In modern parlance, "tapered integration" —whereby a firm produces part of its own requirements and buys the rest from outside suppliers—was used to create a mix of internal, government-run production capacity and external, privately run production capacity. Over the years, as defense needs grew increasingly complex from a technology standpoint and as confidence in the perceived ability of the government to manage and efficiently coordinate the production of such complex systems on its own diminished, the original arsenal model evolved into a small number of so-called GOGO (government-owned, government-operated) defense manufacturing enterprises, which now account for a small and diminishing portion of defense procurement. More commonly, government-owned, contractor-operated (GOCO) arrangements prevail where substantial government investments in highly specialized facilities with little commercial application are required but private enterprise is perceived to be significantly more efficient. Most frequently, however, defense goods and services are provided by private, often-specialized industrial firms focused on the defense market. The purely private enterprises that make up most of the defense industrial base today can, nonetheless, find their actions greatly influenced by a variety of DOD policy tools, which can shape the supply chain for defense systems in significant ways.

EVOLUTION OF THE MILITARY LOGISTICS SYSTEM

The unpredictable and varied nature of the threat spectrum facing our nation today requires a more lethal, responsive, and agile military capability. Logistics is central to the military's ability to respond to a call to action, and the military must adapt. The military logistics system has changed from the Cold War paradigm of supply needs being met by stockpiling massive supplies at successive points along the supply line extending to the battlefront to a just-in-time concept by which the rapid movement of supplies and equipment reduces the need for stockpiles and reserves of supplies but depends instead on detailed and accurate knowledge and prediction of supply and demand (Figure 5-1). Today, military logisticians recognize the need for a new paradigm of combat logistics called "sense and respond" based on real-time information about the supply needs of the warfighter at the frontline. Such a system should rapidly respond to needs, supplying the right things at the right place at the right time across a dispersed battlefield and around the world. This system is based on the most current industrial supply-chain strategies applied to the complex and broad needs of the military supply chain.

In pursuit of this new paradigm, the Defense Logistics Agency (DLA) 2007 Strategic Plan has three strategic thrusts (Defense Logistics Agency, 2004):

- *Extend the enterprise.* Aligning DLA resources geographically closer to the customer.
- *Connect the warfighter demand with the supply*. Establish business process and data links between the military's requirements for materials and the sources of those materials in the industrial base.

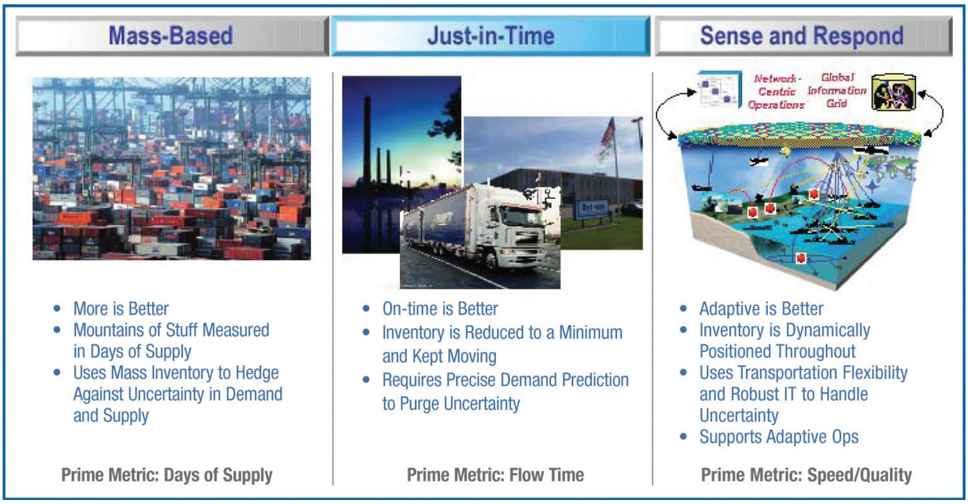

FIGURE 5-1 Logistics transformation. SOURCE: Defense Logistics Agency, 2004, p. 9.

- *Deliver supply chain excellence.* Develop end-to-end logistics solutions that strike the targeted balance between effectiveness, agility, reliability, speed, visibility, and cost. Collaborate proactively with national supply-chain partners in developing logistics solutions.

DLA's implementation strategy includes leveraging industry's capabilities to provide world-class support at the lowest possible cost and adopting and institutionalizing best business practices to improve quality, reduce cycle times and costs, and maintain the integrity of the procurement process. The DLA identifies challenges to this approach, among them that weapons and military systems are changing rapidly with the insertion of high-technology, high-value components; that the industrial base is spread around the globe with fewer U.S. sources for military equipment and supplies; and that "Buy American" legislation limits resort to foreign sources, which may offer higher quality, lower cost products.

Today's modern military logistics system is attempting to integrate responsive and effective supply chain management, and a stockpile is only one of many possible tools for responding to sudden surges in specific requirements or disruptions to vital parts of the supply chain. There are other tools and policy options available to DoD and its suppliers today.

DEFENSE INDUSTRIAL POLICY AND THE POLICY TOOL CHEST

Throughout the Cold War, from the late 1940s to the late 1980s, the lessons of World War II shaped the paradigm for defense industrial policy. The United States was committed to a strategy by which a qualitative technological advantage in the weapons systems it deployed and the number of advanced systems it was able to deploy would guarantee victory in the face of an adversary's apparent numerical superiority. Put simply, the strategy was to first identify a set of capabilities that were deemed critical to U.S. ability to field qualitatively superior advanced weapons systems in the quantities needed to overcome a numerically superior adversary. The role of defense industrial policy was to do what was needed to ensure that the U.S. defense industrial base could meet the challenges of this strategy. This included being able to surge the production of weapons systems should war break out and to continue to produce these systems in sufficient quantity to replace losses in a sustained conflict.

Evolution of Industrial Policy

The job of defense industrial policy was to identify vulnerabilities and deficiencies in the supply chain that could hamper the ramping up of the production of weapons systems in wartime and to make sure the country could maintain the flow of these systems off the production lines to sustain U.S. forces in a continuing conflict. That meant ensuring that the inputs needed to field and use these systems—whether technologically sublime, like advanced electronic components, or vital but mundane, like natural rubber and oil—were available in sufficient quantities.

To fix potential vulnerabilities in the supply chain, problems had to first be identified. The approach was to posit a warfighting scenario, then calculate what was needed to fight the war, prevail, and reconstitute the peacetime stocks of systems needed after the war was over. The scenario might be a short spasm of nuclear war or it might be a long, sustained conventional war with a large and powerful adversary. In either case, industrial planners in the military services and at DoD had to (1) determine which weapons were likely to be deployed and which were likely to be lost and would require replacement, (2) translate these requirements into requirements for U.S. industry, and (3) ensure that the industrial base was sufficiently robust to meet these requirements.

Over the years, tools and techniques for modeling how military scenarios generated industrial requirements evolved and improved. By the end of the twentieth century, it was common to find military planners using simulation models to estimate wartime requirements. These, in turn, were coupled to input-output models developed by economists and used to estimate industrial requirements.

These increasingly sophisticated models did not, however, answer the questions at the heart of any analysis of supply chain vulnerabilities: Which capabilities were truly critical? What about uniforms and berets? Anchor chain? Should allies' industrial capabilities be counted as available to U.S. defense production? If so, who should be counted as a firm ally, and who might waver? Were disruptions to transportation and communication likely to endanger availability from allies, and with what degree of risk? How long might a disruption be expected to last? How quickly could new U.S. capabilities be brought online to replace a foreign supply source, and at what cost? What substitutes might be available? If multiple foreign sources of supply were available, did this diversification in supply mitigate the risk of disruption of any single source? When considering the benefits of a diversified supply base, should the diversity be defined in terms of geography? Equivalently, would one foreign-owned source with 10 industrial facilities scattered around the globe be more or less of a risk than 10 foreign companies each operating a single facility in a different country? How "total" should the wartime mobilization be—what civilian production was truly essential and could not be curtailed, and what consumption could be rationed, restricted, or suspended?

Questions like these typically do not have simple, well-defined, answers. Typically, the related issues have been analyzed in terms of baseline cases and increasingly stressed scenarios and possible answers to the questions have been evaluated in those terms. Inevitably, qualitative judgments about relative risks in best- and worse-case scenarios ultimately inform these analyses.

With the end of the Cold War, the fundamentals of the process described above changed little. Rather, the underlying conflict scenarios used to generate industrial requirements were changed: At first a single major conflict morphed into a series of near-simultaneous lesser conflicts in the 1990s. Then, after 9/11, these threats were joined by a possible asymmetric strike by a nonstate adversary. The qualitative issues discussed above became even more difficult to parse as the single, near-peer, monolithic adversary was transformed in the course of little more than a decade into the larger and more amorphous bundle of lesser state and nonstate actors that dominate the perils of national security planning in the twenty-first century. Today, U.S. defense industrial policy nonetheless remains harnessed to a conceptual framework that was vastly easier to deploy against a single near-peer adversary.

Import Restrictions

One simple method for mitigating the risks of dependence on vulnerable foreign supplies is to simply bar goods manufactured or sourced outside national boundaries from defense procurement. A variety of authorities allow such restrictions. The so-called Berry Amendment[1] requires that all food (except processed or

[1] 10 *U.S.C.* 2533a.

manufactured food), clothing (except chemical warfare protection suits), a variety of specific textile products, and hand and measuring tools purchased by DoD be grown, processed, and manufactured in the United States. (Domestic procurement requirements for specialty metals and authority for waivers in exceptional cases were moved out of the Berry Amendment and into a separate title of U.S. law in the FY 2007 Defense Authorization Act—see discussion of Materials Protection Board, below.) It is far from clear that Berry Amendment commodities were selected on the basis of an analysis of supply chain vulnerabilities and a potential risk to national security.

The Buy American Act, which dates back to the 1930s, basically mandates that all federal procurement—not just that by DoD—give preference to domestically manufactured or produced goods and services. A series of complex waivers and exemptions, however, allows federal agencies to waive this requirement in particular circumstances—for example, if the good is not available domestically in sufficient quantity, or at a reasonable cost, or if it comes from a sanctioned free trade area, like NAFTA or the Caribbean Basin Economic Recovery area, or if it is included in a sanctioned trade agreement, like that on civil aircraft. Most important, perhaps, DoD is granted substantial discretion to purchase foreign goods when doing so is in the interest of national security. DoD has concluded so-called reciprocal procurement memoranda with a variety of foreign nations, granting exemptions from the Buy American Act to these countries in the public interest. DoD can also grant individual exemptions for specific purchases from foreign countries and has done so in the past.

Under Section 232 of the Trade Expansion Act of 1962 (similar authorities existed under earlier legislation as well), the Department of Commerce (DoC) can recommend that the President adjust imports if they are deemed detrimental to national security.[2] DoC is required to consult with DoD, and in practice, DoD's evaluation has played a central role in recommendations to the President. Over the last couple of decades, Section 232 investigations have considered imports of iron ore and semifinished steel, petroleum, integrated circuit ceramic packages, gears, uranium, plastic injection molding machinery, and antifriction bearings.

Restrictive measures of this sort have implications for procurement costs that may not be attractive. By nature, they are not very flexible tools for managing supply chain risks, although discretion for waiver almost always exists if officials are willing to invest significant political capital in exercising this discretion. Import restrictions, if exercised, may also create undesired obstacles to U.S. exports when copied, or retaliated against, abroad. They can, however, reduce dependence on foreign supplies at reasonable cost, but only if they are imposed some time before a crisis.

[2]For further information, see a 2004 report from the DoC at https://www.bis.doc.gov/DefenseIndustrialBasePrograms/OSIES/2-3-2-Reports/232-pamphlet.pdf. Accessed August 2007.

Industrial Subsidy

Under Title III of the Defense Production Act of 1950, DoD is authorized to buy products, possibly at above-market prices, or pay for production facilities as needed for national security purposes. Most recently, this program was used to subsidize the creation of a primary beryllium processing facility in the United States in 2006 (see discussion of beryllium in Appendix F). The Strategic and Critical Materials Stockpile Act creates the authority to expend proceeds from the stockpile on facilities for refreshing, refining, or transforming strategic and critical materials. To the best of this committee's knowledge, this authority was utilized only once, in the 1980s (see section "Cold War Years" in Appendix A).

Technology Promotion

Investing in new technology is a routine DoD function, and R&D programs administered by the military services, the Defense Advanced Research Projects Agency (DARPA), and joint defense organizations like the Missile Defense Agency (MDA) are commonly used to find technological solutions to defense problems. Some of these R&D initiatives have been in materials—composite materials, high-strength steel, ceramics—and could be applied to issues like creating substitutes for scarce materials or reducing the amounts of scarce materials in the formulation of defense systems components through new designs. Indeed, there are many examples of R&D initiatives being used to deal with resource scarcities in response to a security threat (development of synthetic rubber and of synthetic fuels and biofuels as a replacement for jet fuel).

If a vital manufactured material is a defense concern, and the material is protected by a patent monopoly in the hands of an insecure or uncertain source, there is ample authority under the World Trade Organization and U.S. patent law to require a compulsory license be issued to a U.S. producer. However, access to the actual technology—as opposed to the legal right to use the technology—assumes that the technology is available from friendly sources; if it is not, some technology investment may be required to create the needed access.

Restrictions on Foreign Investment

Under Title VII of the Defense Production Act, the U.S. government may review the proposed acquisition of U.S. companies by foreign nationals and may block such mergers or require divestiture of sensitive activities if they are deemed to be a security concern (U.S. Department of the Treasury, 2006). This authority has been and continues to be used to preserve U.S. control of activities and technologies that concern national security. Some of these interventions have been where the supply chain for strategically significant components and materials was the issue. In some cases, the mere initiation of an investigation has dissuaded a foreign investor, and the formal inquiry was terminated before an actual decision had been made. According to a 2006 Congressional Research Service report, since 1988 the Committee on Foreign Investment in the United States (CFIUS) has received more than 1,500 notifications and conducted a full investigation of 25 of them. Of the 25 cases, 13 were withdrawn upon notice that CFIUS would conduct a full review and 12 of the remaining cases were sent to the President. Of these 12 transactions, one was prohibited. The transaction that was prohibited by the President involved the acquisition in 1990 of Mamco Manufacturing Company by the China National Aero-Technology Import and Export Corporation (CATIC).[3]

This tool has historically been used only with the greatest reluctance and caution. Frequent use could encourage other nations to intervene on proposed U.S. investments abroad more often and on similar grounds, which could ultimately greatly harm U.S. economic interests by impeding attempts to secure U.S. supply chains by investing overseas in foreign sources of supply.

Direct Allocation of Production

Under Title I of the Defense Production Act, DoC, acting in coordination with DoD, can move orders for goods and services ahead of civilian orders in production queues when required for national security. The Defense Priorities and Allocations System (DPAS) administered by DoC can issue ratings for orders to prime contractors that give them production priority over nonrated orders. Further, prime contractors receiving rated orders are obliged to pass these to their subcontractors, ensuring that needed materials and components produced by the subcontractor are also given priority over other competing demands.

Legal authority for this system stops at U.S. border, making the legal situation for foreign subcontractors in receipt of a rated order from a U.S. prime contractor rather murky. A foreign subcontractor doing business in the United States clearly has some incentive to cooperate with the system. But what happens if there are conflicting demands on the foreign contractor from its own legal framework or national government? How such conflicts might be solved is unclear and even friendly governments have, on occasion, declined to require a contractor to cooperate with the U.S. DoD. Indeed, there are even cases where an ally's interpretation of its own export control laws has hindered U.S. military access to a foreign-produced input.[4]

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[3]Mamco manufactured metal parts for civilian aircraft, primarily for Boeing of Seattle, including tail and wing assemblies and small parts like brackets (Jackson, 2006).

[4]See OTA (1991, pp. 119-120) on dual-use electronic components and NRC (1995, p. 4) on rocket engines and flat-panel displays.

Here, globalization has definitely reduced the domain where U.S. policy for securing the defense supply chain holds sway.

Relationships and Diplomacy

Finally, the formation of political alliances and blocs—for example, NATO, the Waasenaar Group, the International Energy Agency, and other groupings—can influence the actions of other governments with respect to imports, exports, and other forms of cooperation relevant to supply chains for military critical items. Similar, though less formal, cooperative arrangements can also be found in the private sector, which frequently relies on relationships, information gathering, technology, and position within the industry to compel or influence links with their chains of supply.

SUPPLY CHAIN TOOLS AND VULNERABILITIES

In the face of increasing globalization and industrial consolidation (such as the mining industry examples discussed elsewhere in this report), companies are implementing supply chain management techniques to improve their performance and minimize their liabilities. Supply chains have become increasingly complex, with supplier and vendor networks stretching around the world. Diversification of suppliers can reduce risk by introducing redundancy, while increased reliance on outsourced operations can increase risk. Private corporations have adopted a range of strategies to give them the flexibility to offset these risks, including detailed risk analyses and contingency sourcing plans. Some of these techniques include developing multiple sources or deep supplier partnerships and investing to develop recycling as a source of supply or to develop substitute materials.

Transportation becomes a critical factor in global supply chains, and the use of short-term reserves or inventories is sometimes appropriate to mitigate the effects of temporary supply disruptions. In the United States, better supply chain management has succeeded in reducing inventory costs from 6.1 percent of GDP in 1984 to 3.1 percent in 2005 and logistics costs from 13.4 percent to 9.5 percent in the same period.

Figure 5-2 shows the ratio of the value of private sector inventories to private sector final sales over the first quarter of 1972 to the first quarter of 2007. The ratio of private nonfarm inventories to final sales of goods and services fell from about 3.5 in 1981 to about 2.3 in 2006, a decline of about 34 percent. It is worth noting that private inventory to sales ratios have remained roughly constant since the last quarter of 2001 (after September 11) and may have even risen slightly, after a long decline. This suggests that the post-9/11 perception of risk attributable to the disruption of global supply chains may actually have affected business behavior.

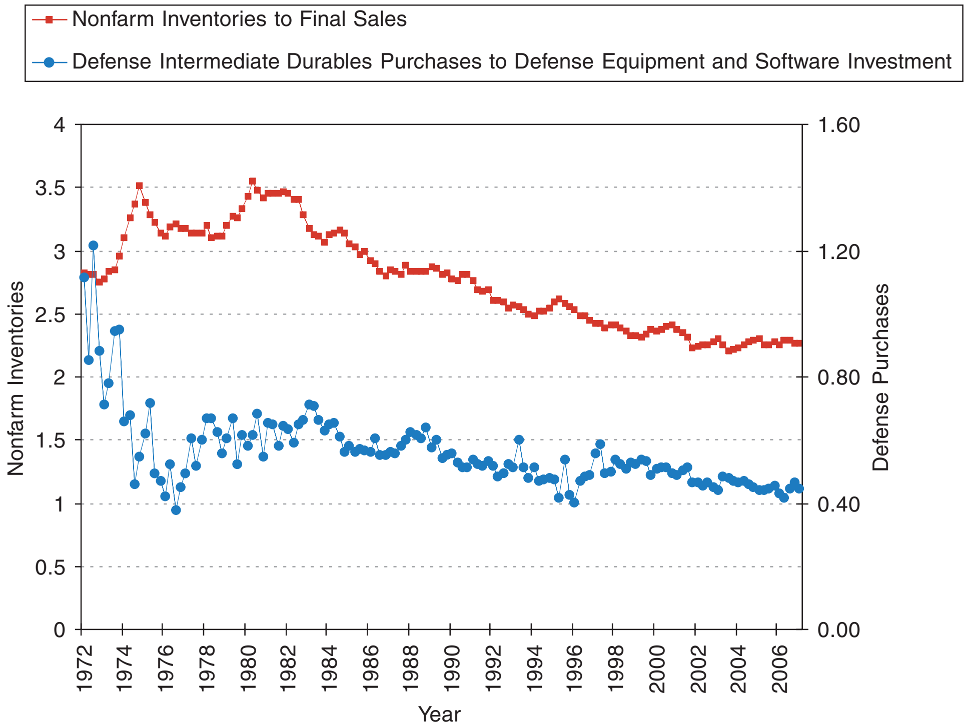

FIGURE 5-2 Ratio of the value of private sector inventories to private sector final sales from the first quarter of 1972 to the first quarter of 2007. Data are from taken the national income accounts published every year by the Bureau of Economic Analysis.

The committee is unaware of any DoD-wide estimate of the value of inventories of goods held by DoD and its contractors that could be compared to DoD procurement to arrive at a comparable inventory/sales ratio. The closest analogue that is available in the national income accounts would be to divide purchases of intermediate durable goods for production of defense goods and services, by the value of final finished investment in defense equipment and software. (There was a high degree of variance in the 1970s, when the Vietnam war was winding down.) Interestingly, this value declined over time much as did private sector inventories—from about 0.63 in 1981 to about 0.44 in 2006, for a decline of about 30 percent.

Supply Chain Tools for NDS-Related Scenarios

Corporations have a variety of tools to manage their supply-chain liabilities (Box 5-1). While these tools may be used in different ways in the commercial and

BOX 5-1
Supply Chain Tools

- Inventory management, including a safety/emergency stock when necessary but with an emphasis, more often than not, on minimizing inventory.
- Dual sourcing, with a split in requirements on an 80/20 basis with the proviso that the secondary supplier could and would cover 100 percent of requirements during a crisis. A crisis mode might include but not be limited to strikes, acts of nature, work stoppages, political events, or terrorist incidents.
- Alternative sourcing, including the possibility of using substitute or recycled inputs for the manufacturing process.
- Relationship building to establish and consolidate a preferred relationship with the supplier so that if something happens the supplier will feel a strong obligation to satisfy the company's needs because it is always hard to deny a friend.
- Establishment of a knowledge base on supply to understand the demand history and any political issues surrounding supply.
- Establishment of a database on current technologies (refining/processing) to understand current capabilities available to the company and predict future improvements, substitutions, or new supplies.
- Better tracking so that when supply chains become longer, new tools such as global positioning equipment can monitor shipments from source to destination.
- Disaster/incident plans to model the impact of major disruptions across the corporation in a quantitative way and to put action options in place as a response. These kinds of plans and models have specific durations: short term (2-3 weeks), medium term (4-6 weeks), and long term (more than 6 weeks).
- Cooperation with stakeholders—for example, working with government agencies to obtain information and with industry groups and associations to pool resources in the event of an incident.

government sectors, the basic concepts are applicable in both cases. Several of these tools (inventories, recycling, and the search for substitute materials) clearly apply to the kinds of scenarios the NDS was established to address.

Use of Inventories

In contrast to the strategy behind the NDS, the strategy today for improving the efficiency and effectiveness of supply chains is to avoid holding a reserve at any point in the supply chain by, in effect, replacing inventory with information. A lean production system means smaller industry inventories—trading off the robustness of supply chains against the cost of holding reserves.

> More rapid demand planning information, combined with more accurate sales forecasts, combined with transparent information on the supply chain's operations to meet demand, lowers the need for excess inventory in the supply chain. (Mentzer, 2001)

Scrap and Domestic Recycling

Over the past decades, the United States and other industrialized countries have accumulated large amounts of resources in the form of infrastructure, buildings, machinery, and so on. In addition to the materials accumulated in these secondary resources, materials are also tied up in wastes, such as tailings, slag, or municipal solid wastes. The amount of iron stock incorporated in products in use, for example, is about the same as the amount of iron stock in identified domestic ores (Figure 5-3).

As ore grades continue to decline, scrap recovery is generally becoming more competitive. So while primary mining resources are decreasing in size and ore

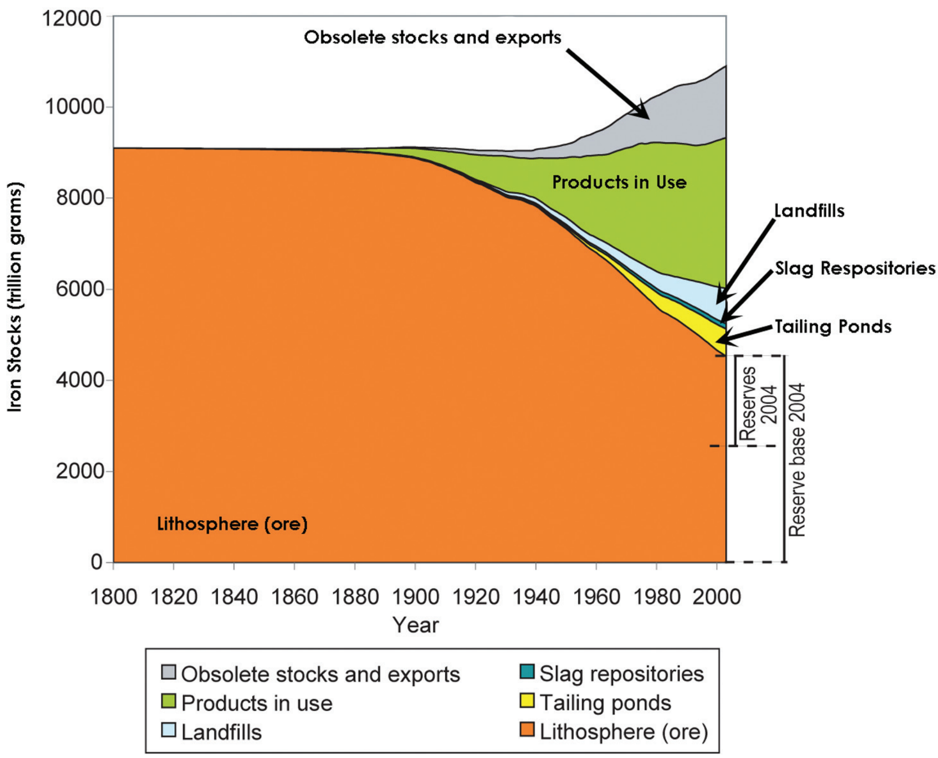

FIGURE 5-3 Historic iron stocks in the United States in trillions of grams. "Reserves" include all identified ores that can be mined economically given current prices and technology. The "reserve base" includes economic, marginally economic, and parts of currently subeconomic resources. SOURCE: Müller et al. (2006). Copyright 2006, National Academy of Sciences.

grade, the availability of secondary resources is expected to increase significantly in the future, following roughly the trend of increased materials production in recent decades with a delay dependent on product lifetimes. In contrast to primary resources, secondary resources become available mainly in developed countries that once consumed large quantities of products.

The United States, while dependent on imports of various materials, is a major exporter of scrap. Many emerging market economies in Asia (particularly China) are currently building new infrastructures and technologies to recover a variety of materials from discarded products of Western countries, such as electronic wastes.

Recycling can be an environmentally friendly and economically attractive alternative supply of raw materials. Generally speaking, it is an underutilized resource, although owing to the sharp increases in mineral prices (Figure 3-1) it is gaining more attention in the private sector. As an example, in the aerospace industry it is now common practice to account for every pound of prime metal used in, for instance, the manufacture of a jet engine. Any excess metal is typically fed into a closed-loop recycling operation in which all the recyclers must (1) be approved by the manufacturers and (2) provide certified assays of the revert material that is utilized. The scrap recovered in this way can exceed the manufacturing requirements by 25-40 percent or more. The hard metals industry has similar programs in place to recover tungsten, cobalt, titanium and tantalum. The electronics industry is attempting to institute similar recycling programs for batteries, but doing so is labor intensive, and collecting and sorting remain problematic. In the chemical industry, the main challenges are collecting, sorting, and processing, and the use of recycling varies depending on the recovered material's price. The importance of price as an impetus for recycling can be illustrated by the recycling of catalytic converters—an activity that while labor intensive is becoming more prevalent because the precious metals involved are so expensive. With today's historically high prices for minerals, the markets for scrap are international and the competition for these materials has become global, with China being a dominant buyer across the board.

Price alone is not likely to be a compelling reason for DoD to adopt the recycling of important materials. While public concern for the environment may be an impetus for government-supported recycling programs (both existing processes and new ones), the more likely reason for DoD to consider recycling as an alternative source of materials is if those recycling sources are domestic or from countries identified as close allies. An effective recycling program would involve the establishment of a database of trusted companies currently doing recycling, their capabilities, capacity, technologies implemented, and the industries served. Also it would involve identifying trusted sources of scrap—closed loop or open loop.

Substitutes

The substitution of another material for a critical material in short supply is a valid tool for supply chain management. As with the examples of using inventories and recycling, supply and price are the drivers for making such substitutions in civilian application, and substitution may be a good option for defense systems as well. A decision to pursue substitution is motivated by the answers to these questions:

- How is the performance of the technology affected by the substitution?
- How does the cost of the material being replaced compare with that of the substitute material?
- Is the substitute material classified as dangerous to the environment and regulated by the Environmental Protection Agency?
- How available is the substitute, and what is the potential for disruption of its supply?
- Is the substitute material available from a friendly country?
- Is the new product recycle-friendly and environment-friendly?
- Is the substitution compatible with the direction of the technology in question?

The search for a replacement refrigerant in air-conditioning equipment was driven by the financial motivation for replacing the ozone-depleting freon in use at the time. Today, China's having placed export restrictions on such rare earth minerals as yttrium, lanthanum, and cerium may hasten the development of substitutes for these materials, whose loss would be felt rather quickly. For instance, yttrium is utilized in the cracking catalysts used to produce gasoline and jet fuel. Lanthanum is used in electronics, and cerium is used in polishing glass. Rhenium, not a rare earth mineral but very rare nevertheless, is being added to many alloys to increase the wear and life of aerospace turbine blades. Recovering many of these materials is difficult and recycling even more so, making substitution the only attractive route.

Risk Analysis and Mitigation Strategies

Understanding today's critical material supply vulnerabilities (Box 5-2) is crucial to knowing which tool is appropriate for a particular supply chain and when and where is should be applied. Supply chain analysis for Cold War scenarios recognized that the United States was dependent on offshore sources for some critical minerals and metals and that the greatest risks to supply were associated with offshore operations, including mining, overland transport, and ocean delivery. Once on U.S. soil, the commodity was relatively secure against foreign disruption and

BOX 5-2
Risk of Disruptions to the Supply Chain

The supply chain manager has to consider where the potential threats are in the supply chain that could impede the production or movement of critical materials and components. This is particularly true if a given supply chain is dependent on a single U.S. source for a specific part of the supply chain. Examining the types of disruptions that could occur, the threats can be classified under three categories—physical disruption, political/social disruption, and market disruption.

Physical Threats to Production and Transport

- Military attack on the U.S. homeland—conventional, weapons of mass destruction (WMD), electromagnetic pulse, and so on;
- Military conflict involving attacks on foreign sources, production, and infrastructure;
- Naval conflict and maritime attack on sea lanes and ports;
- Terrorist attacks and sabotage (conventional and WMD); and
- Natural disasters (hurricanes, tornados, storms, earthquakes, floods, fire).

Political/Social Threats to Production and Transport

- Export controls (embargoes, reallocations, restrictions, and taxes) by foreign governments with anti-U.S. strategic interests;
- Political turmoil and social unrest in foreign countries;
- Labor action and strikes, foreign and domestic;
- Epidemic diseases in foreign countries;
- U.S. import controls; and
- Government prohibitions against use.

Market Threats

- Higher prices and delayed delivery due to market imbalances such as increased demand and reduced supply;
- Foreign ownership that has monopolistic control of sources and/or transport and that disfavors U.S. purchases; and
- U.S. industrial restructuring and consolidation, resulting in a cutback to a single source or no domestic source whatsoever.

Supply chains also have other vulnerabilities such as human error, a lack of preparedness or training, inadequate management of the supply chain for a critical material, inflexibility, and fragility.

military attack. Today's global market for minerals, materials, and manufactured products means that the United States is more dependent on foreign sources along the full length of the supply chain. Today, ore, processed materials, and even finished components may be produced overseas for U.S. military markets. This increase in foreign dependence makes the United States more vulnerable to disruptions of the foreign production of these materials and their transport. Increased inventories could be a hedge against disruptions to the supply of critical defense materials but would run counter to the pressure on companies to reduce inventories.

The committee recognizes that the supply chain for each material has its own particular vulnerabilities. In some cases, the U.S. portion of the supply chain dominates and there is little or no foreign sourcing. In other cases, there may be few (or no) U.S. links in the chain and near-total dependence on offshore links.

Manufacturers and purchasers of end items manage this supply chain for best value, producing or assuring the supply of goods and components of the right quality, at the right price, and on the right delivery terms in a changing, dynamic market. Such lean and agile supply chains depend on reliable, secure, and efficient production, communication, transport and distribution. Supply chains are vulnerable to disruption if a critical supply node or link fails and goods cannot be moved forward. At worst, disruptions stop delivery. At best, they cause short delays and increase direct costs.

Table 5-1 shows the different threats against the nodes and links of a typical supply chain. With a greater dependence on foreign sources and less on domestic sources, the full range of physical, political, social, and market threats against foreign and domestic sources produces a much more vulnerable supply chain. Also, political vulnerabilities are a much more important disruptive factor today.

The effect of lean operations can be seen by looking at what happened to the movement of goods across the border with Canada after the tragic events of September 11, 2001. With the closure of the border in the aftermath of the terrorist attacks, auto industry operations were forced to shut down as far away as Tennessee due to a shortage of supplies (Andrea and Smith, 2002). How a single source could significantly disrupt supply became clear in July 1993, when a fire in a single Sumitomo epoxy resin plant knocked out 60 percent of the global supply of high-grade resins used to package integrated circuits. Prices for memory chips doubled within a few weeks (McCausland, 1993; Robertson and Levine, 1993). Industry accounts at the time quoted Robert Costello, former Deputy Undersecretary of Defense, previously the leader of a Pentagon campaign to decrease U.S. supply chain vulnerability: "U.S. dependency only becomes a momentary issue when something happens. Everyone gets very excited, but as time goes on, they forget about it, and nothing is done until the next crisis comes along" (Robertson and Levine, 1993).

On the transportation side, a critical vulnerability is the concentration of ocean shipment through a limited number of major U.S. (and foreign) ports. For example, the Los Angeles port terminal handled 190 million revenue tons of cargo, 8.5 million TEU containers, and 2,900 ships in 2006. A terrorist attack and closure of the terminal would have a catastrophic impact on U.S. trade and the domestic economy.

TABLE 5-1 Threats and Vulnerabilities Matrix for a Global Supply Chain

	Mining, Processing, and Component Producers		Shipping Terminals		Transport Mode			
Type of Threat	Offshore	U.S.	Foreign	U.S.	Ocean Bulk	International Air/Sea	Foreign	U.S. Domestic
Physical								
Local military attack	x		x			x	x	
Naval attack			x	x	x			
Terrorism/sabotage/accident	x	x	x	x		x	x	x
Natural disaster	x	x	x	x		x	x	x
Political/social								
Export control/restrictions	x							
Political turmoil	x		x			x	x	
Labor strikes	x	x	x	x	x	x	x	x
Epidemic disease	x		x		x	x	x	
U.S. import controls	x		x			x		
Market								
Higher prices and delays	x	x			x	x		
Foreign ownership/monopoly	x	x	x	x	x	x	x	x
Domestic restructuring		x						

In summary, each supply chain has different vulnerabilities that can be assessed by answering three questions: What can go wrong? How likely is it that the negative event will happen? How serious are the consequences of the negative event? The vulnerabilities of a given supply chain must be evaluated in terms of their time and cost consequences and the probability of their occurrence. Vulnerability will be low if a commodity or component is available from multiple sources through redundant distribution channels. On the other hand, if it is available from only one or two production sites or if one company or country has dominant market share and control, its supply chain may be very vulnerable to disruption. A vulnerability assessment will show where the most likely and most damaging disruptions could occur along a particular supply chain. High-cost, high-probability threats must be planned for, and preventive plans and actions should be taken to decrease their impact and to improve reliability. Specific actions will balance risks and costs to provide a flexible and robust supply chain.

In the final analysis, supply chain vulnerability assessment is about the detailed and methodical identification and assessment of risks and the development of mitigation strategies. Risk identification and mitigation must be accompanied by a dispassionate and well-founded analysis of the types of potential disruption, the probability of occurrence, and the downside risk should such a disruption materialize.

Specific examples of disruptions to materials supply chains are presented in Table 5-2.

OTHER MODELS FOR STOCKPILE POLICY

The committee concludes its consideration of policy tools and supply-chain management tools by briefly describing other U.S. models for stockpiles of materials and other usables. (These stockpiles are discussed in more detail in Appendix E.) These other models provide insights into how government can assure the supply of a particular item or commodity. Of most interest to the committee's work is an examination of how the stockpiled usables are released and managed.

First established in 1999, the Strategic National Stockpile (SNS) program contains large quantities of medicine and medical supplies to protect the U.S. public in the event of a public health emergency—for example, terrorist attack, a flu outbreak, or an earthquake. The SNS is designed to deliver medicines within 12 hours to any state in the United States once federal and local authorities agree that local supplies have run out. To receive SNS assets, the governor of an affected state or someone designated by the governor can request their release. Once the request has been made, the Director of the Center for Disease Control and Prevention has the authority, in consultation with the Surgeon General and the Secretary of Health and Human Services, to order the deployment of the SNS. His or her decision to do so

TABLE 5-2 Recent Supply Disruptions

Year	Material	Major Source	Problem	Effect
1978	Cobalt	Congo	Rebels invaded copper-cobalt mining region in Congo.	Rapid rise in price.
1993-1994	Antimony	China	Flooding was alleged reason though some industry sources believe Chinese suppliers withheld material to increase price.	Price per pound rose from $0.80 to $2.28 in 1995 and from $1.61 in 2005 to $2.25 in 2006.
1994	Titanium (rutile). Key in producing titanium metal.	Sierra Leone has one of the largest deposits of rutile.	Production suspended when rebels invaded mining sites.	Global shortage.
2001	Tantalite. Used for capacitors.		Closure of facility in Australia for long-term maintenance.	Shortage, price rise, and smuggling from central Africa.
2005	Tungsten	China dominates supply and restricts amount produced and exported.	Exports reduced due to alleged inadequate supplies within China, the largest consumer.	Steep price increase.
2005-2006	Rhenium. 65 percent goes to aerospace (jet engine blades and rocket nozzles).	75 percent from two companies—Molymet in Chile (50 percent) and Redmet in Kazakhstan (25 percent).	Redmet exports blocked due to dispute over debt with copper company that supplies Redmet.	Price rose from $1,000/kg to $6,000/kg. Known future production increases are already sold.

SOURCE: USGS Minerals Management Service.

may be based on evidence of an overt release of a biological or chemical agent or some other emergency that might adversely affect the public's health.

Medical materiel stocked in the SNS program is rotated and kept within potency shelf-life limits by means of quarterly checks to ensure quality, annual inventory of all items, and inspections of environmental conditions, security, and overall integrity of packaging. One noteworthy aspect of the SNS is vendor-managed inventory (VMI). VMI supplies are stored by the pharmaceutical vendors rather than by the government in its warehouses until an incident requires the shipment of pharmaceuticals or other medical supplies beyond those held by the stockpile program. VMI supplies arrive within 24 to 36 hours of their being requested.

The Strategic Petroleum Reserve (SPR), established in 1975 following the 1973-1974 oil embargo, is the world's largest supply of emergency crude oil. The federally owned oil stocks are stored in huge underground salt caverns along the coastline of the Gulf of Mexico. At the time or writing, the SPR can hold 727 million barrels.[5]

Decisions to withdraw crude oil from the SPR are made by the President under the authorities of the Energy Policy and Conservation Act. In the event of an energy emergency, SPR oil would be distributed by competitive sale. It takes 13 days from the time of the Presidential decision for the oil to enter the commercial market. The President can order a full drawdown of the reserve to counter a "severe energy supply interruption" or a limited drawdown. In addition, the Secretary of Energy is authorized to carry out test drawdowns and distribution of crude oil from the reserve. The SPR has been used under emergency circumstances only twice (during Operation Desert Storm[6] in 1991 and after Hurricane Katrina[7] in 2005). DOE has the authority to exchange oil from the reserve, and these exchanges have been used to replace less suitable grades of crude oil with higher-quality crudes. Interestingly, DOE may also release supplies for limited, short-duration assistance to petroleum companies to resolve oil delivery problems. For instance on June 21, 2006, the Calcasieu ship channel was closed to maritime traffic owing to the release of a mixture of storm water and oil near Lake Charles, Louisiana, cutting off supplies to refiners in the area. Deliveries to the Conoco Philips and Citgo refineries in the area were disrupted. To avert the temporary shutdown of both refineries, the SPR agreed to loan 750,000 barrels of sour crude. The loaned amount was repaid in early October 2006.[8]

A little known government stockpile is the federal helium reserve, which contains more than 1 billion cubic feet of helium gas stored at the Cliffside storage facility in Texas. The Helium Privatization Act of 1996 directed the U.S. Department of the Interior to commence the sale of 85 percent of the Federal Helium Reserve by 2015. Sales from the helium reserve commenced in 2003 and at the time of writing of this report, about one third of the reserve had been sold in five sales

[5]For information on the current SPR inventory, see http://www.spr.doe.gov/dir/dir.html. Accessed May 2007.

[6]For further information see http://www.fossil.energy.gov/programs/reserves/spr/spr-drawdown.html#desertstorm. Accessed May 2007.

[7]For further information see http://www.fossil.energy.gov/programs/reserves/spr/spr-drawdown.html#katrina_sale. Accessed July 2007.

[8]For further information see http://www.fossil.energy.gov/programs/reserves/spr/spr-drawdown.html. Accessed, July 2007.

on the open market. A fifth sale is planned in the fall of 2007, but this time against the backdrop of a helium shortage (Spivey, 2007). No releases other than the sales have been made in recent years.

Although not a stockpile per se, one U.S. government program—the Civilian Reserve Air Fleet (CRAF)—seeks to maintain surge capacity for military crises and gives private industry an interesting role. CRAF involves commitments by U.S. airlines (both passenger and cargo carriers) to provide airlift capacity (cargo, passenger, and medevac services) to the U.S. military on relatively short notice (24 to 48 hours). Carriers are required to convert their aircraft to meet specific military requirements within the surge period and place them under the temporary command of the Air Force Air Mobility Command. Air carriers participating in CRAF do not receive any direct payments for maintaining aircraft that can be converted on short notice to meet military requirements. Instead, their participation is rewarded by eligibility for peacetime military air transportation contracts. CRAF has been activated only twice in the program's 54-year history, in the 1991 Desert Storm action (August 1990-May 1991) and during the U.S. military action in Iraq (February-June 2003).

The CRAF model has important lessons for materials stockpiling. Military procurement contracts could be structured to reward contractors who maintain larger inventories of critical materials and/or components. Language could be included within procurement contracts that establishes supply-availability targets (for example, 30 days) for key materials that are deemed essential to a particular weapons system or program. Such private-stockpile targets would require appropriate compensation arrangements.

MATERIALS STOCKPILES IN OTHER COUNTRIES

The committee was able to gather information on two foreign-held materials stockpiles, one in Japan and one in China.

Japanese Stockpile

The Japanese government has maintained a materials stockpile since 1983. At present, seven materials are stockpiled: nickel, chromium, tungsten, cobalt, molybdenum, managanese, and vanadium. The government-managed stockpile seeks to maintain an amount equal to 42 days' consumption as its contribution to an overall goal of 60 days' consumption. An explicit component of Japanese stockpiling policy is the encouragement of private firms to maintain stockpiles equal to 18 days' national consumption of these materials.

According to briefings provided to the committee, the choice of these seven materials for the Japanese stockpile was based on their criticality to Japan's steel industry, which loomed much larger within the Japanese economy in 1983 than it does today. Like the U.S. stockpile, Japan's stockpile is based very much on perceptions of economic vulnerability at a particular (distant) point in time. Briefings to the committee indicated that the composition of the stockpile is now being reviewed.

Japan's government manages its stockpile so as to avoid supply and price disruptions for these commodities. Briefings to the committee indicated that sales of materials from the stockpile can be triggered if their price rises above the average during the preceding 5 years. Three releases of nickel from Japan's stockpile occurred during 2006. The agency in charge of the stockpile (Japan Oil, Gas, and Metals National Corporation, JOGMEC) can undertake a release from the stockpile unilaterally, without having to seek the permission of its parent agency (METI) or the Japanese national legislature.[9]

Chinese Stockpile

Information about China's strategic commodities stockpile(s) is sketchy.[10] Recent shortages have led Beijing to reconsider its stockpile policy, levels, and processes and to expand its existing stockpile administration. China's mineral reserves are reported as holding copper, iron ore, bauxite, and manganese and, more recently, rare earths, chromium, and aluminum. Energy reserves include uranium, coal, oil/petroleum, and natural gas.

Section 3 of China's latest 15-year development plan (Chinese National Development and Reform Commission, 2007) calls for strengthening the management of mineral resources. It says the country's strategy should be to

> improve the system for stockpiling important resources, enhance the national stockpile of important mineral products, and adjust the structure and layout of the stockpile. Combine the national stockpile and users' stockpile, and impose a requirement for compulsory reserves at firms consuming a lot of resources.

The main point is that China sees a growing need to enhance and increase its stockpiles in critical or strategic materials. This plus the growing involvement of China and some other developing countries in the world's stock markets could impact U.S. decisions on stockpiling. Even if these are temporary effects, they can still disrupt the system in place.

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[9]For more information on JOGMEC, see http://www.jogmec.go.jp/english/index.html. Accessed November 2007.

[10]For information on China's stockpile, see the following sources: China Daily (2002, 2007); Chinese Commission of Science (2006); Energy Bulletin (2006); Kosich (2006); Mulveron (2006); Oster et al. (2007); Pillsbury (2000); Teo and Neely (2007); U.S. Geological Survey (2007).

CONCLUSIONS

When the NDS was begun, military suppliers were the fabricators of weapons, munitions, and supplies and worked mainly with raw materials from stock. From a supply-chain perspective, bulk materials were relatively near the manufacturing process. Today's suppliers of weapons and munitions to the military are increasingly integrators of systems, as opposed to fabricators, and the supply chain that feeds the integrator has become a network of many interconnected suppliers and manufacturers. Dealing with risk in the supply chain and defining and assessing the magnitude of the risk arising from any possible supply chain disruption has become more complex and requires a much more sophisticated analysis capability than the present approach to modeling materials requirements.

As shown above, a range of policy tools can affect industrial supply chains. Holding a stockpile might be one of many ways to manage the supply of materials for defense, perhaps a tool of last resort. It is a tool that other governments are using but that industry uses only when absolutely necessary. Planning and then building a robust supply chain can mitigate the risk of surges in requirements, unexpected shortfalls in inputs, and the rapid and effective insertion of new materials and manufacturing methods. The challenge is to anticipate and plan for volatility of demand that could adversely impact the supply chain. Our national strategic objective regarding critical defense materials is to ensure the timely availability of the materials to defend our country and its citizens from adversaries. DoD has to be able to actively manage and plan for critical materials shortfalls that could seriously disrupt the military supply chain. The task becomes more complex as new materials and technology are developed and eventually introduced into military systems and old materials become obsolete and noncritical.

Vulnerabilities in the supply chain represent risks to the ability of the military to respond. More detailed analysis of the supply chain for each military system would help to identify risks to mobilization. There are at least three complementary ways to mitigate risks: (1) assess the risks in order to make better informed decisions on ensuring them (for example, deciding if stocks need to be held); (2) spot vulnerabilities in the supply chain and redesign it to eliminate or mitigate them before disruptions occur; and (3) design and manage the supply chain to be more resilient to disruption. Weaknesses in the supply chain may not always be self-evident a priori; they often reveal themselves only when a system is exercised, such as in wartime. One way to learn about supply chain risks is to analyze supply chain disruptions to gain insight into causal factors or systemic issues. Supply choke points or surge demand response issues may point to the need for holding greater inventory at various stages of the supply process.

In deciding if a stockpile is the most appropriate tool for assuring the supply of a particular material, it will be important to take into account (1) the quality of the material, how it may degrade, and if its usefulness could diminish over time; (2) how long it would take to get a material to where it is needed; and (3) the total costs of supplying, storing, and maintaining the material. In addition, the management of any system for supplying critical materials must be dynamic and based on knowing which materials are needed, how much of each, and whether substitutes are available. Assuring the supply of a material might also rely on more than one policy tool simultaneously or sequentially depending on the circumstance. Different tools can provide redundancy to better assure supply.

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6

Current Operational Practices of the National Defense Stockpile

The National Defense Stockpile (NDS) was conceived after World War II as a vehicle for managing risks to the U.S. military-industrial complex posed by shortages arising from military conflicts—see Chapter 4 for a discussion of the evolution of military planning. Over the lifetime of the NDS, its composition and inventory levels of strategic and critical materials have changed considerably as it prepared for a potential mobilization. In the early days, these materials included minerals as well as other supplies such as rubber, whale oil, and goose down. But the environment the NDS operates in is much different. U.S. defense strategy and wartime planning have changed substantially; the globalization of manufacturing and the supply of raw materials has taken hold; and supply chains and the tools for their management have evolved.

Currently, the U.S. maintains in peacetime the military forces that are considered necessary for potential conflicts, reducing the need for a major mobilization and expansion of force levels. To the extent that military production needs to be expanded in response to a conflict, the expansion will be to replace lost equipment or manufacture new equipment to address new threats experienced during the conflict. In response to these changes in force planning and in estimates of the reliability of foreign materials suppliers, the materials requirements and the inventory of the stockpile have changed considerably over the decades. However, there have been significant lags at a number of points: between changes in military planning and the scenarios used for modeling stockpile requirements, between stockpile requirements and legislated stockpiles goals, and between goals and NDS inventory levels.

After the end of the Cold War, stockpile materials requirements dropped precipitously. By 2005, the inventory of goal materials[1] had declined to $90 million for only three materials, identified by a materials requirements decision process. Understanding that process has been a central pillar of the committee's assessment of the relevance of the configuration the NDS and its assessment of what general principles might be applied to the operation of some future stockpile-like activity.

PROCESS TO IDENTIFY STOCKPILE MATERIALS REQUIREMENTS

The NDS operates under the authority of the Strategic and Critical Stock Piling Act.[2] This act provides that strategic and critical materials be stockpiled by the U.S. government to decrease and preclude, when possible, a dangerous and costly dependence by the United States upon foreign sources for supplies of such materials in times of a national emergency. Under the law, the Department of Defense (DoD) is required every other year to recommend requirements for materials already in the stockpile and others it believes should be in the stockpile. Each biennial report includes assumptions used in making the recommendation. The act directs that those assumptions be based on a military conflict scenario consistent with the assumptions used for budgeting and defense planning purposes. Essentially the law mandates that the process for setting materials requirements include a conflict scenario defined by the following:

- The length and intensity of the assumed conflict;
- The structure of the military force to be mobilized;
- The losses anticipated from enemy action;
- The military, industrial, and essential civilian requirements to support the national emergency;
- The availability of strategic and critical materials from both foreign and domestic sources during the mobilization period, the military conflict itself, and the subsequent period of replenishment, taking into consideration possible shipping losses; and
- Civilian austerity measures required during the mobilization and conflict periods.

According to the law, stockpile requirements are to be set for those strategic and critical materials the United States needs to replenish or replace within 3 years of the end of a military conflict scenario, based on the principles outlined above.

[1]A goal material is not available for sale from the NDS.
[2]*U.S. Code* 50, Subchapter III—Acquisition and Development of Strategic Raw Materials.

They are to be based on replenishing all munitions, combat support items, and weapons systems that would be required after such a military conflict.

At the time management of the NDS was moved to DoD, a change was made: A more detailed analytical economic modeling of materials supply and demand was developed as the foundation of the requirements identification process. The modeling was and continues to be coordinated and executed by the Institute for Defense Analyses (IDA) under contract to the Defense Logistics Agency (DLA), the parent agency of the National Defense Stockpile Center. The Office of the Secretary of Defense reviews the results of the IDA modeling and makes recommendations to the Congress.

Which Materials Are Considered?

The legislation governing the NDS says

> For the purposes of this Act: (1) The term "strategic and critical materials" means materials that (A) would be needed to supply the military, industrial, and essential civilian needs of the United States during a national emergency, and (B) are not found or produced in the United States in sufficient quantities to meet such need. (2) The term "national emergency" means a general declaration of emergency with respect to the national defense made by the President or by the Congress.

The strategic materials in the NDS inventory as of May 2007 are listed in Table 6-1. The distribution by commodity type and by value, as reported in the most recent *Strategic and Critical Minerals Report to the Congress*, is shown in Figure 6-1. Of all these materials, only two (beryllium and quartz crystals) were being actively retained at the time of writing this report (June 2007). All the other materials were determined to be in excess and are being sold off. But how is the determination made about which materials to hold given the revolutionary changes in the armed forces over the last half century and, by extension, the material needs of those forces.

Process for Setting Materials Requirements

There are three broad groups of strategic materials for which stockpile requirements are determined: standard materials, specialty materials, and nonmodel materials (DoD, 2005). In this most recent analysis, requirements were determined for 36 standard materials based on econometric modeling of the supply and demand for strategic and essential civilian materials needs under specified conflict scenarios (Table 6-2). Requirements were also estimated for 17 specialty materials (Table 6-3). The requirements for the three nonmodel materials—that is, beryllium, mica, and quartz—were based on interagency consultations chaired by the DLA.

The modeling process estimates the demands on the economy (industry) for essential civilian and defense goods and services; the resultant demand for strategic and critical materials (SCMs); and the shortfalls in those SCMs by comparing the useable SCM supplies with the SCM demands. Any materials that fall short of these estimates become candidates for stockpiling.

There are three pillars in the modeling process that IDA uses: military planning, large-scale econometric models to forecast materials needs, and forecasts of domestic and foreign supplies.

Factoring in Military Planning

The prevailing military scenario of the time is at the heart of the modeling process that leads to a determination of NDS requirements. The NDS requirement process is, therefore, strongly linked to U.S. defense planning through the National Military Strategy or the National Defense Strategy, which are based on periodic reviews of the prevailing threats to the United States and U.S. interests. The strategic construct underlying DoD's force planning has changed over time and can be expected to change (at least marginally) every 4 years, when a quadrennial defense review (QDR) is mandated. Chapter 4 discusses the recent evolution of military planning in some detail, but essentially the approach to force planning has been largely based on the need to be able to fight two nearly simultaneous conflicts and, possibly, another smaller conflict. Though the process tries to anticipate future conflicts, by its nature force planning has historically reacted to rather than anticipated them.

Extraordinary military demands for a given conflict scenario are estimated using a force mobilization model known as FORCEMOB. A multitude of variables need to be considered for a given scenario, including the duration of the conflict, the number and types of forces, the rate of mobilization, the consumption rates of expendables, transportation needs, and so on. FORCEMOB is used by DoD to model the effect on the U.S. industrial base of an extraordinary military demand during conflict and reconstitution. It is one component of the Joint Industrial Mobilization Planning Process, an analytic process that links warfighting needs with industrial capabilities. FORCEMOB considers demands from the armed services and takes into account the capacities of an economy-spanning set of industries, including industries that would be affected, although only secondarily, by a military conflict.

Factoring in Large-Scale Econometric Models

The two quantitative models that have been developed to calculate detailed industry demands given an economic scenario are also pillars of the materials requirements process undertaken by IDA. Demands for goods and services are

TABLE 6-1 Stockpile Inventory as of May 2007

	Material	Unit	Recommended Requirement	Inventory (No. of Units)	Value ($ millions)	Share of Total Value (%)
1	Aluminum oxide					
	Aluminum oxide abrasive grain	ST		3,737	1.287	0.090
2	Beryllium					
	Beryllium copper master alloy	ST		86	0.483	0.030
	Beryllium metal vacuum cast	ST		13	1.386	0.100
	Beryllium metal HPP	ST	50	171	68.400	3.420
3	Chromium					
	Chromium, ferro, high carbon	ST		203,352	160.095	11.320
	Chromium, ferro, low carbon	ST		100,624	119.721	8.560
	Chromium metal	ST		5,825	26.095	1.840
4	Cobalt	lb Co		2,269,165	38.508	2.720
5	Columbium					
	Columbium metal ingots	lb Cb		22,156	0.295	0.020
6	Diamond industrial stones	ct		473,405	4.734	0.330
7	Fluorspar					
	Metallurgical grade	SDT		1,327	.019	0.001
8	Germanium metal	kg		1,988	15.667	1.110
9	Iodine	lb		1,685	0.015	0.001
10	Manganese					
	Manganese ore, metallurgical grade	SDT		360,972	3.476	0.250
	Manganese, ferro, high carbon	ST		551,068	318.732	22.530

11	Mercury	lb		9,781,604	0.000	0.000
12	Mica					
	Muscovite block stained and better	lb		1,674	0.001	0.000
	Muscovite splittings	lb		15,025	0.011	0.000
13	Platinum group metals					
	Iridium	tr oz		2,061	0.494	0.030
	Platinum	tr oz		8,380	5.722	0.400
14	Quartz crystals	lb	15,520	15,582	0.027	0.000
15	Quinidine	av oz		142	0.000	0.000
16	Talc, steatite block and lump	ST		956	0.134	0.010
17	Tantalum group					
	Tantalum carbide powder	lb Ta		3,802	0.138	0.010
18	Tin	MT		7,933	70.504	4.980
19	Tungsten group					
	Tungsten metal powder	lb W		585,619	19.583	1.380
	Tungsten ores and concentrates	lb W		48,816,497	527.218	37.270
20	Vegetable tannin extract					
	Quebracho	L		11,008	0.918	0.06
	Wattle	L		120	0.003	0.000
21	Zinc	ST		13,428	30.765	2.170
	Total				1,414.489	100.000

NOTE: Just three materials (chromium, manganese, and tungsten) accounted for 76 percent of the inventory. In addition to the materials in this table, the inventory contains talc (ground) valued at $0.058 million. This material is neither strategic nor critical. ST, short ton; lb, pound; ct, carat; kg, kilogram; SDT, short dry ton; tr oz, troy ounce; av oz, avoirdupois ounce; MT, metric tonne; and L, liter.
SOURCE: Supplied to the committee by the Defense National Stockpile Center, June 2007.

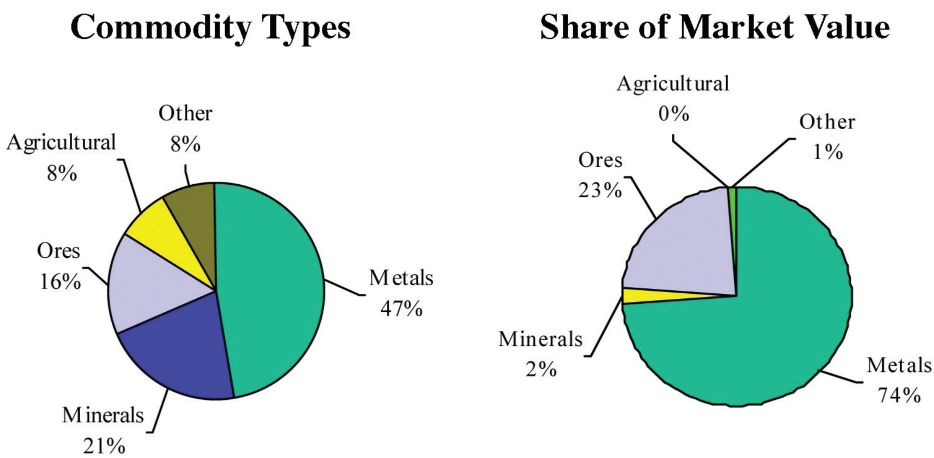

FIGURE 6-1 Stockpile inventory as of September 30, 2005. The inventory was valued at $1.59 billion. SOURCE: DoD (2006).

TABLE 6-2 Standard Materials Examined in the 2005 NDS Study, with NDS Inventories as of March 31, 2005

		Inventory	
Material Name	Unit	(No. of Units)	(million $)[a]
Aluminum metal	ST	0	0.00
Aluminum oxide, fused crude	ST	0	0.00
Antimiony	ST	0	0.00
Bauxite, metal grade, Jamaica and Suriname	LDT	0	0.00
Bauxite, refractory	LDT	0	0.00
Bismuth	lb	0	0.00
Cadmium	lb	0	0.00
Chromite, chemical, refractory, and metallurgical grade ore	SDT	0	0.00
Chromium, ferro	ST	611,496	532.18
Chromium, metal	ST	6,824	25.21
Cobalt	lb Co	4,718,104	56.75
Columbium[b]	lb Cb	581,913	0.73
Copper	ST	0	0.00
Fluorspar, acid grade	SDT	4,884	0.30
Fluorspar, metallurgical grade	SDT	87,062	0.62
Iridium (platinum group)	tr oz	18,797	1.94
Lead	ST	37,180	22.00

TABLE 6-2 Continued

		Inventory	
Material Name	Unit	(No. of Units)	(million $)[a]
Manganese dioxide, battery grade, natural	SDT	708	0.02
Manganese dioxide, battery grade, synthetic	SDT	2,971	0.12
Manganese, ferro	ST	705,316	339.33
Manganese metal, electrolytic	ST	0	0.00
Manganese ore, chemical and metallurgical grades	SDT	440,614	5.25
Mercury[c]	L	128,705	0.00
Molybdenum	lb	0	0.00
Nickel	ST	0	0.00
Palladium (platinum group)	tr oz	5,000	1.29
Platinum (platinum group)	tr oz	15,880	10.51
Rubber (natural)	L	0	0.00
Silicon carbide	ST	0	0.00
Silver	tr oz	0	0.00
Tantalum	lb Ta	857,177	24.39
Tin	MT	24,724	161.31
Titanium sponge	ST	757	4.33
Tungsten	lb W	61,135,061	210.69
Vanadium	ST V	0	0
Zinc	ST	68,607	59.13
Total			1,456.08

NOTE: ST, short ton; LDT, light displacement tonne; lb, pound; SDT, short dry ton; tr oz, troy ounce; MT, metric tonne; and L, liter.

[a]In millions of March 31, 2005, dollars. Dollar valuations represent "realizable stockpile values" as of March 31, 2005, and might be higher or lower than current market value. In general, NDS commodities are subject to substantial price fluctuations depending on changing market conditions.

[b]Includes 532,371 pounds of columbium contained in columbite/tantalite ore. The ore is valued for its tantalum content (included in the tantalum data above). The columbium in the ore is valued at zero.

[c]Although other parties continue to trade in mercury, the realizable stockpile value of the NDS inventory is zero.

SOURCE: DoD (2005).

estimated for a set of 320 industry sectors that span the entire U.S. economy using the Long-term Interindustry Forecasting Tool (LIFT) model developed by the Interindustry Forum at the University of Maryland.[3] LIFT is a large-scale model of the U.S. economy that builds up macroeconomic forecasts, and it is used to understand industry behavior in response to market conditions by calculating industry sectoral outputs based on econometric forecasts of demand for each good, as well as the dynamically changing structure of the economy. The LIFT model also calculates prices for each industry, based on unit intermediate costs and value added.

[3]See http://www.inforumweb.umd.edu/index.html. Accessed June 2007.

TABLE 6-3 Specialty and Nonmodel Materials Examined in the 2005 NDS Study, with NDS Inventories as of March 31, 2005

Material Name	Unit	Inventory (No. of Units)	Inventory (million $)[a]
Specialty materials			
Beryllium (HPP) metal[b]	ST	171	89.64
Beryllium copper master alloy	ST	0	0.00
Beryl ore	ST	3,848	0.28
Boron	MT	0	0.00
Boron composite filaments	MT	0	0.00
Boron nitride	tr oz	0	0.00
Gallium	kg	0	0.00
Germanium	MT	31,627	18.90
Hafnium	lb	0	0.00
Indium	tr oz	0	0.00
Rhenium	lb	0	0.00
Rhodium (platinum group)	tr oz	0	0.00
Ruthenium (platinum group)	tr oz	0	0.00
Tellurium	MT	0	0.00
Yttrium	MT	0	0.00
Zirconium metal	ST	0	0.00
Zirconium ores and concentrates	SDT	0	0.00
Subtotal			108.81
Nonmodel materials			
Mica, muscovite block, condenser quality, fair stained and better[c]	lb		0.00
Quartz crystal	lb		0.03
Subtotal			0.03
Total			108.84

NOTE: ST, short ton; MT, metric tonne; tr oz, troy ounce; kg, kilogram; lb, pound; and SDT, short dry ton.
[a]In millions of March 31, 2005, dollars. Dollar valuations represent "realizable stockpile values" as of March 31, 2005, and might be higher or lower than the current market value. In general, NDS commodities are subject to substantial price fluctuations depending on changing market conditions.
[b]The realizable stockpile value shown does not reflect current market prices.
[c]The small value of the muscovite block mica in the NDS appears as zero due to numerical rounding.
SOURCE: DoD (2005).

Also used is the Interindustry Large-scale Integrated and Dynamic Model (ILIAD) model that translates the forecast from LIFT to a finer level of industrial detail. ILIAD maintains detail for 320 industrial sectors and calculates outputs, imports, prices, and employment (Inforum, 2007).

The quantities of the strategic and critical materials needed to produce the forecast goods are then estimated using materials consumption ratios (MCRs), which are estimates of material consumed per dollar of industrial output in a given sector and are used to convert an estimate of industry output to demand for a specific material in that sector. MCRs are based on available data on materials consumption in manufacturing sectors across the economy and are developed with assistance of the Department of Commerce, the U.S. Geological Survey (USGS), and the Census Bureau.

Factoring in Supplies from Domestic Sources and Reliable Foreign Sources

The third pillar of the process is the supply of strategic and critical materials from domestic sources and reliable sources of strategic and critical materials. Supply forecasts are compared, on a time-phased basis, to the forecasted materials demands of the United States over the duration of the particular conflict scenario, which can include a reconstitution phase. Factors affecting materials supply forecasts include assessments of the threat posed by potential enemies and other hostile countries and estimates of the reliability of foreign infrastructure, foreign excess capacity, and the risk of domestic port damage. An important set of variables is those for country reliability which express the U.S. vulnerability to supply disruption by nations that may be unfriendly or uncooperative to the United States and its interests during a time of crisis—all these factors depend on the nature of the conflict scenario. Generally, reductions in the imports of strategic materials are assumed to occur at the start of a military conflict and allowed to run for the entire duration of the scenario being modeled.

The Outcomes—Materials Requirements

At the final point in the modeling process, integrating the military planning scenarios, the econometric models, and the supply scenarios results in a detailed time-phased picture of the supply and demand for each modeled strategic and critical material over the duration of the conflicts. It is from this analysis that potential shortfalls in the supply of strategic and critical materials are identified and stockpile requirements established.

IDA completes the modeling process, first for what is called the base case, which involves a variety of scenarios coupled with the U.S. macroeconomic outlook and reliability factors for foreign suppliers, as discussed above. The elements of the conflict scenarios are based first of all on the guidelines in the legislation that governs the NDS. The scenarios also make certain assumptions about the nature of the conflict—including the length and intensity, the size and types of military forces to be mobilized, and the potential losses that could be incurred. The modeling process is then also run for various what are called stressing excursion scenarios, both less stressed and more stressed, whereby other disrupting events that could occur during the conflict are introduced to determine the sensitivity to base assumptions and to estimate the full range of possible SCM supply and demand. Possible disruptive events include a partial disruption of oil supplies from the Middle East, uncertainties about the reliability of countries that supply SCMs, alternative economic scenarios in the United States, including a sudden fall in the value of the dollar ("dollar shock"), and variations in demand in the civilian economy during a conflict.

STOCKPILE REQUIREMENTS AND GOALS

The committee was somewhat surprised, given the complexity of the IDA process for modeling materials requirements, that since 1999 the NDS requirements as reported to Congress have remained largely unchanged despite the considerable changes that have occurred, as discussed throughout this report, in globalization, U.S. industrial capacity, the status of U.S. mining operations, and military planning.[4] All this change notwithstanding, in the past four requirements reports—with the single exception of the 2001 report, which identified a requirement for antimony—the DoD has consistently reported to Congress the same three materials requirements: mica, quartz, and beryllium hot-pressed powder metal. The committee decided, therefore, that the details require closer inspection.

The committee had trouble comparing DoD-recommended materials requirements with the materials goals set by Congress since DoD's requirements reports are more frequent than the legislation establishing specific goals. Although the goals are established in authorization legislation that is enacted annually, they have been set not annually but only every few years.

Before the 1990s, the Congress tended to accept the DoD's recommendations and the relevant goals were set. But as the stockpile moved into a sales mode in the early 1990s, while Congress continued to request that DoD provide it with a report on stockpile requirements, Congress did not automatically accept the department's recommendations. As a consequence, the legislated goals were at times higher than DoD requirements, and sales of materials considered excess by DoD were delayed while awaiting legislation authorizing their sale. It is noteworthy, however, that in recent years, there has once again been little difference between DoD requirements and legislated goals. At the time of writing, the last authorization was in FY2002 and was effective December 12, 2001.

Table 6-4 shows the NDS requirements from 1989 to the present and Table 6-5 shows the materials goals from 1999 to the present. After the end of the Cold War,

[4]The DNSC provided copies of the DoD reports to Congress on the NDS requirements from 1989 to 2005 (DoD, 1989, 1992, 1993, 1995, 1997, 1999, 2001, 2003, 2005).

TABLE 6-4 DoD-Recommended Requirements (millions of dollars)

Year	DoD-Recommended NDS Requirements	Total Value of NDS Requirements	Comments
1989	Aluminum metal Aluminum oxide Antimony Asbestos (chrysotile) Bauxite Beryllium Bismuth Cadmium Chromite Chromium Cobalt Columbium Copper Cordage fibers (sisal, abaca) Diamond Fluorspar Germanium Graphite Iodine Jewel bearings Lead Manganese Mercury Mica Morphine sulfate Nickel Platinum Pyrethum Quartz Quinidine Quinine Rubber Sebacic acid Rutile Silicon carbide Silver Tantalum Titanium sponge Thorium nitrate Tin Tungsten Vanadium Vegetable tannin (three varieties) Zinc Iridium Composites (rayon fiber, silver) Rhodium Ruthenium	13,000.00	The recommended list was deemed an interim NDS requirement as this was the first report utilizing a new methodology, pending a completion of the analyses of requirements for about 11 percent of the stockpile materials not addressed in the report as well as a completion of additional consultations with civil agencies on mobilization planning assumptions. The recommended additions reflected applications of military strategies and advances in weapons system technologies not included in previous analyses, as well as upgraded forms of materials and additional materials needed to accelerate military production during an emergency. For the 1989 report, the DoD base case would have required a stockpile with a total inventory valued at $7.3 billion. However, legislated requirements (50 U.S. Code 98a(b)) that mandate the purpose of preventing “a dangerous and costly reliance on imports for strategic and critical materials during a national emergency” drove down the import reliance from the DoD base case and drove up requirements (to be consistent with law) to $13 billion.

continued

TABLE 6-4 Continued

Year	DoD-Recommended NDS Requirements	Total Value of NDS Requirements	Comments
1992	Bauxite Chromite Chromium Cobalt Columbium Graphite Manganese Mica Nickel Platinum Quartz Natural rubber Tantalum Titanium sponge Tungsten Beryllium Diamond (industrial) Jewel bearings Germanium Iridium	3,297.00	The $3.3 billion requirement was based on the statutorily mandated scenario. This included a new war scenario provided by the Joint Staff and "reflects that part of the political, economic, and military restructuring in Eastern Europe and former Soviet Union that could be accommodated within the statutorily mandated requirement for a global war of at least 3 years duration," revised mobilization force structure targets, revised forecasts for the civilian economy, revised assessments of the reliability of foreign suppliers of materials. The proposed goal of $3,297 million was $5,714 million less than the value of inventory held in the NDS at the time. To meet the recommendations of the 1992 recommendations, NDS inventory would need to increase for some materials (for example, titanium sponge, natural rubber, tantalum) and decrease for other materials (for example, tin, zinc, lead). DoD recommended that Congress give DoD authority to impose a moratorium on NDS acquisitions and authorize DoD to liquidate $1 billion in NDS inventory and to amend the Strategic and Critical Stockpiling Act to reflect changes in planning assumptions. An alternative scenario was proposed based on a 1-year mobilization and a 3-month war with total NDS requirements of $1.32 billion, almost $2 billion lower than the statutorily mandated scenario.

TABLE 6-4 Continued

Year	DoD-Recommended NDS Requirements	Total Value of NDS Requirements	Comments
1993	Chromium Graphite Mercury Mica Platinum Beryllium Jewel bearings	444.00	Largest requirements were for platinum ($219 million), beryllium ($108 million), and Jewel Bearings ($48 million).
1995	Platinum Tantalum Quartz	24.00	
1997	Bauxite Iridium Nickel Mica Quartz Beryllium	43.87	No acquisitions would be needed to meet requirements.
1999	Beryllium HPP metal Mica muscovite block Quartz crystal	13.15	Civilian sector estimates are lower in the 1999 base case as a result of a change in methodology to solve supply-demand mismatch problems that led to systematic overestimates of nonconflict demands for NDS materials relative to supply in the 1997 report as well as in prior years' assessments. Mica and quartz are nonmodel materials, beryllium is an advanced material. Requirements for these materials were estimated off-line and based on special studies conducted by IDA. (The committee did not have any documentation on this process.) Largest single requirement, which is an ongoing requirement, is for 50 ST of HPP beryllium.

continued

TABLE 6-4 Continued

Year	DoD-Recommended NDS Requirements	Total Value of NDS Requirements	Comments
2001	Antimony Beryllium HPP metal Mica muscovite block Quartz crystal	10.65	The antimony requirement results from changes in projected foreign supplies in 2001 planning scenarios. Largest single requirement, which is an ongoing requirement, is for 50 ST of HPP beryllium.
2003	Beryllium HPP metal Mica muscovite block Quartz crystal	89.71	Largest single requirement, which is an ongoing requirement, is for 171 ST of HPP beryllium.
2005	Beryllium HPP metal Mica muscovite block Quartz crystal	157.00	The number of specific materials with shortfalls varies from 5 in the base case to 15 in the more stressful scenario, and 3 in the less stressful case. The materials identified in the more stressful case were antimony, bauxite, beryllium, bismuth, boron nitride, cobalt, fluorspar, mica, palladium, quartz crystal, natural rubber, tin, titanium sponge, tungsten, and yttrium. Most influential variables are foreign excess capacity and foreign infrastructure reliability on the supply side, nonessential civilian demand, and dollar shock on the demand side. Largest single requirement, which is an ongoing requirement, is for 171 ST of HPP beryllium.

SOURCE: DoD reports to Congress (1989, 1992, 1993, 1995, 1997, 1999, 2001, 2003, 2005).

TABLE 6-5 NDS Goals from the NDS Materials Reports from 1998 to the Present (millions of dollars)

Report Date and Effective Date	Materials with Stockpile Goals[c]	Total Inventory Value	Value of Stockpile Goals[d]	Value of Excess Inventory for SCM Goals[d]	Comments
NDS report date[a] 1/7/1999 Effective date of goals[b] 11/17/1998	Bauxite, refractory Beryllium Chromium, ferro, high carbon Chromium metal Jewel bearings Manganese, ferro, high carbon Iridium Palladium Quartz Tantalum metal, powder Tantalum metal Thorium nitrate	4,100	611	728	Goals follow from enactment of FY1999 Authorization and Appropriations Act. NDS inventory notes that the inventory for mica is "neither strategic nor critical." A deficit of inventory of 18,324 ST of chromium metal with an associated value of $85 million is noted. A deficit of some 53,726,779 pieces of jewel bearings with no associated value is noted.
NDS report date[a] 1/14/2000 Effective date of goals[b] 10/05/1999	Bauxite, refractory Beryllium Chromium, ferro, high carbon Chromium metal Jewel bearings Manganese, ferro, high carbon Iridium Palladium Quartz Tantalum metal, powder Tantalum metal Thorium nitrate	3,374	113	583	Goals follow from enactment of FY2000 Authorization and Appropriations Act. NDS inventory notes that the inventory for mica is "neither strategic nor critical." A deficit of some 53,726,779 pieces of jewel bearings with no associated value is noted.

continued

TABLE 6-5 Continued

Report Date and Effective Date	Materials with Stockpile Goals[c]	Total Inventory Value	Value of Stockpile Goals[d]	Value of Excess Inventory for SCM Goals[d]	Comments
NDS report date[a] 1/16/2001 Effective date of goals[b] 10/05/1999	Bauxite, refractory Beryllium Chromium, ferro, high carbon Chromium metal Jewel bearings Manganese, ferro, high carbon Iridium Palladium Quartz Tantalum metal, powder Tantalum metal Thorium nitrate	2,909	59	504	Goals follow from enactment of FY2000 Authorization and Appropriations Act. NDS inventory notes that the inventory for mica is "neither strategic nor critical." A deficit of some 53,726,779 pieces of jewel bearings with no associated value is noted.
NDS report date[a] 1/18/2002 Effective date of goals[b] 12/28/2001	Beryllium Quartz	2,483	7.83	43.4	Goals follow from enactment of FY2002 Authorization and Appropriations Act. NDS inventory notes that the inventory for mica is "neither strategic nor critical." 99% of total value of the goals and 97% of the value of excess NDS inventory for goals are associated with beryllium.

NDS report date[a] 2/12/2003 Effective date of goals[b] 12/28/2001	Beryllium Mica Quartz	2,483	7.28	40.5	Goals follow from enactment of FY2000 Authorization and Appropriations Act. >99.99% of total value of the goals and >99.99% of the value of excess NDS inventory for goals are associated with beryllium. Crystal quartz is reported to have no monetary value. 300 lb mica is now listed as an NDS goal.
NDS report date[a] 3/9/2004 Effective date of goals[b] 12/28/2001	Beryllium Mica Quartz	1,711	20	48.4	Goals follow from enactment of FY2000 Authorization and Appropriations Act. >99.99% of total value of the goals and >99.99% of the value of excess NDS inventory for goals are associated with beryllium. Crystal quartz is reported to have no monetary value. The change in value of goals and inventory of materials with goals is associated with a 275% increase in unit price.

[a] Date of transmittal cover letter.
[b] Date of the corresponding authorization bill.
[c] For each year listed here, the NDS goals are calculated by subtracting disposal authority from either the goal in effect or the inventory quantity on the date the disposal authorization was effected by Congress, whichever was lowest.
[d] Calculated from tables in NDS reports.

SOURCE: DoD (1998, 1999, 2001, 2003, 2004, 2005, 2006).

the committee found that DoD requirements declined more rapidly than the legislatively authorized goals. This may be partly because requirements reports are issued more frequently than the goals are changed in law. While excesses or shortfalls in the inventory have generally become disposition or acquisition goals, respectively, there has not been one-to-one correspondence between the goals for the stockpile and the requirements based on modeling; the reason for this discrepancy is not altogether clear.

Evolution of the NDS Econometric Model

A review of DoD's reports to Congress on the NDS requirements from 1989 through 2005 shows how these modeling efforts have evolved over time. The underlying structure of the model has remained remarkably constant. The Office of the Under Secretary (Policy) gives the Joint Staff a war planning scenario, and based on this scenario the Joint Staff develops detailed time-phased production requirements for weapons systems and other materiel. Current inventories and assumptions about consumption, attrition, and other variables are used in developing these requirements. A "translator" is used to aggregate wartime procurement by DoD into a set of demands for output by U.S. industry. An input-output model then determines the total demands on all U.S. industries associated with wartime defense procurement. To defense total demand on U.S. industries (that is, taking into account intermediate goods purchased from other industries that are used in the production of defense goods) is added nondefense total demand (that is, civilian demand) for goods purchased from these same industries. The resulting defense and nondefense demands are then compared to supply available from U.S. industrial capacity and imports. Any apparent shortfalls stimulate additional investment in industrial capacity.

The resulting total industry demands by sector are then multiplied by a set of detailed material input coefficients that are developed through a separate process. These material input coefficients are based on historical data and have not included any direct impact of higher prices in stimulating substitution or reducing consumption. (Civilian austerity assumptions and the definition of "essential civilian demand," it might be argued, implicitly reflect the effects of some unspecified price-driven substitution reducing demand for nonessential civilian goods.) The resulting demands for modeled materials are compared to estimates of available imports and U.S. production of those same materials, derived primarily from data supplied in early years by the U.S. Bureau of Mines and in later years by the U.S. Geological Survey. Available imports reflect assumptions about disruption and the reliability of supplies developed through another process. Any deficits in net supply of the studied materials generate requirements for inventories to be held by the NDS.

Civilian demands are based on macroeconomic forecasts of overall economic growth coupled to a module translating an overall economy-wide forecast of growth (a macroeconomic forecast) into growth rates in civilian demand by industry. The resulting profile over time for civilian demand by sector is then adjusted for reductions in "nonessential civilian demand," which reflect assumptions about austerity measures imposed during wartime, formulated by DoD in collaboration with civilian agency advisors.

Noteworthy developments in the evolution of this modeling framework over time include the following:

Assumptions About War Scenarios

All scenarios historically have been provided by the Under Secretary of Defense for Policy and do not reflect independent judgments by the Under Secretary of Defense for Acquisition, Technology and Logistics or by IDA. From 1989 to 1993, DoD requirements reports assumed a conflict of indefinite duration and modeled materials requirements for the first 3 years of the conflict. The 1989 report assumed 1 year of warning, in which materials stocks could be built up; the 1992 report dropped the assumption of a warning year, and the 1993 report added a 3-year mobilization period coupled to a reduced force structure. The 1993 report assumed that the indefinite-duration conflict would be a nonnuclear, conventional war, so the NDS requirement for beryllium was dropped.

The 1995 report hypothesized 7 to 9 years of warning, 2 to 4 years of mobilization, and an approximately 3-year-long conflict—3 to 4 months of intense conflict, followed by a 2-year stalemate, followed by another 3 to 4 months of concluding conflict. There continued to be no beryllium requirement.

From 1997 through 2001, the assumptions were two major theater wars (MTWs) with little warning. Beryllium was added as an "off-line," special-study-based requirement in 1997.[5] The 1999 scenario specified a 1-year duration for the MTWs, followed by a 3-year regeneration period. The 2001 scenario continued these assumptions.

In 2003, the MTWs were renamed "major conflict operations" (MCOs) but otherwise continued the overall 2001 assumptions. In 2005, the assumptions were altered to include, within a single year, a catastrophic attack on a U.S. city, two nearly concurrent MCOs, and a smaller scale contingency. As before, the 1 year of conflict followed by a 3-year regeneration period drove requirements models.

[5]"The beryllium metal goal recommended in this report is based in part on requirements that assume a need for renewed production of nuclear weapons. This is a rare exception to DoD's policy of basing recommendations for NDS goals solely on the minimum scenario guidance in the Stock Piling Act." (DoD, 1997 Report to the Congress on National Defense Stockpile Requirements, June, p. 6)

Input-Output and Macroeconomic Models

From 1989 to 1992, the input-output model and macroeconomic growth forecasts for the civilian economy were provided by the Defense Research Institute. From 1993 through 2005, the University of Maryland's Inforum group provided these models.

Civilian Austerity and Essential Civilian Demand Assumptions

The 1989 report specified that civilian motor vehicle demand would fall by 50 percent in the first year of a 3-year conflict, followed by a 75 percent reduction in year 2 and a 100 percent reduction in year 3. Residential construction was assumed to drop 50 percent in year 1, 67 percent in year 2, and 75 percent in year 3. Other structures dropped 25 percent in year 1 and 50 percent in years 2 and 3. In later reports, these assumptions grew into more finely specified reductions in civilian spending: In 2005, the assumptions included reductions in autos, boats, aircraft, and recreational vehicles, jewelry, foreign travel, auto accessories, other consumer durables, gasoline and oil, and both residential and nonresidential construction. Consumer spending reduced by austerity was shifted into other categories of consumption.

The 1995 report assumed that emission controls on motor vehicles would be relaxed in wartime, so no stockpile requirement for platinum or palladium was recommended. The high dollar cost of a platinum stockpile was mentioned as a justification for this assumption.[6] Reports after 1995 returned to the assumption that emission controls would not be relaxed; apparently other changes in assumptions were sufficient to ensure that there would be no requirement for high-value platinum.

Materials Consumption Ratios

Reports from 1989 through 1993 were based on static materials consumption coefficients derived from data from the early 1980s. These were not updated until the 1995 report. Reports from 1997 on updated at least some of these coefficients as part of the modeling process.

[6]"For all these reasons, it would be unwise to stockpile very expensive (platinum group metals) for a very unlikely need." (DoD, 1995 Report to the Congress on National Defense Stockpile Requirements, May, p. 3)

New Materials

As previously remarked, requirements for indium, rayon, rhodium, and ruthenium were specified by DoD in 1989. These "new stockpile materials" became the basis for a new category of "advanced materials," with requirements determined by special off-line studies. In 1992, this category included five materials (the above four plus germanium). By 2003, it had grown to 19 advanced materials (including, as the committee has noted, beryllium). It is noteworthy that the econometric modeling methodology was not made use of in determining requirements for these newer materials.

Other Changes

The treatment of investment in new capacity appears to have been refined substantially over time. The 1995 requirements report excluded partially finished weapons and platforms produced during a conflict period from materials requirements; prior and later reports continued to count such work in progress toward materials requirements. Finally, the methodology for calculating availability of imports, based on supplier reliability and risks of disruption, has also been much refined over time.

Close Look at Identified Requirements

Of course, over the history of the stockpile there were times when Congress and the administration had different policy perspectives. There were also instances when DoD did not propose in its annual budget to fund the acquisition of materials required to meet projected shortfalls. The reason for this is also unclear. A case in point is the most recent materials requirements report from DoD, which identified requirements for only three materials even though the IDA process had identified a potential shortfall in a number of materials.

The IDA report in question, also the most recent at the time of writing, was issued in 2005 following IDA's analysis of 55 materials. Five materials were identified that might experience supply shortfalls in the base case, 15 were flagged in the more stressful scenario, and 3 in the less stressful case. The 15 materials in the more stressful case were antimony, bauxite, beryllium, bismuth, boron nitride, cobalt, fluorspar, mica, palladium, quartz crystal, natural rubber, tin, titanium sponge, tungsten, and yttrium. The most influential variables in modeling the shortfalls in the more stressful case were foreign excess capacity and foreign infrastructure reliability on the supply side and nonessential civilian demand and "dollar shock" on the demand side. The largest single requirement, which is an ongoing requirement, was 171 short tons of hot pressed powder (HPP) beryllium, valued at $89.6 million as of March 31, 2005.

It is noteworthy that despite the different outcomes listed above, the 2005 DoD report to Congress recommended the stockpiling of only three materials: HPP beryllium metal, mica, and quartz crystal. The committee was also struck by the fact that these three materials requirements resulted not from the IDA analysis but from the interagency process, which involved a more subjective analysis of the potential for a disruption in the supply chain. Specific materials currently in the inventory, along with the recommended requirements as of May 2007, are shown in Table 6-1. Mica is no longer a required material. DoD has indicated to the committee that the requirement for stockpiling mica was dropped after one of the services indicated that it no longer needed that mineral. The committee notes also that that both quartz and beryllium are being held to guarantee a supply in peacetime and not just for use in a national emergency. Although the peacetime supply is important for defense, it seems to be inconsistent with the currently stated purpose of the stockpile. A case study for beryllium is contained in Appendix F.

CONCLUSIONS ON THE CONFIGURATION OF THE STOCKPILE

At the center of the operation of the NDS, there has been a continual refinement of the models and of the inputs to the models, as well as refinement of the interagency process for vetting assumptions. This is a considerable effort that has resulted in the accumulation of significant expertise and the ability to identify materials requirements on the basis of a high-caliber input-output economic approach. But is the econometric approach yielding results that reflect actual military needs? What of the legal framework within which the NDS operates? Because both concerns affect the configuration of the NDS, the committee believes a comprehensive assessment of the NDS is warranted. Clearly, since the end of the Cold War the need for the NDS appears to be waning. The changes in the IDA modeling process—for example, changing supplier reliability estimates, military planning, and so on—have resulted in outcomes that predict minimal materials requirements. There have been no upgrades or acquisitions since 1997, and NDS inventories have fallen in value from over $15 billion in the mid-1980s to about $1 billion in 2007, with further declines anticipated. The predicted materials requirements have also fallen in value from a high of some $20 billion in 1991 to three materials valued at approximately $100 million in 2005. This quick look at the situation leads one to wonder what the point is of having a stockpile.

Conclusions on the Setting of Materials Requirements and Goals

Looking back at the history of the stockpile (Chapter 2), the most dramatic swing in stockpile requirements and the concomitant shift in U.S. policy toward the stockpile since World War II occurred in the late 1980s and into the 1990s in the aftermath of the Cold War. Conflict scenarios underwent sharp revision and the reliability of foreign suppliers of materials was reevaluated. While it is to be expected that in a given year the requirements for a given material may be higher or lower than current amount held in the stockpile, the data in Figure 6-2 show not much of a relationship between the value of stockpile goals—that is the materials identified as being required and authorized to be held—and the value of the actual inventory in the stockpile, even over the long term. Stockpile goals have varied considerably depending on the policy for assessing requirements at the time, and inventory, with an exception in the early 1980s, just declines steadily.

The modeling methodology used to estimate stockpile requirements has undergone significant refinement since 1988. While limitations exist for all econometric models, and the committee has not undertaken an in-depth audit of the models

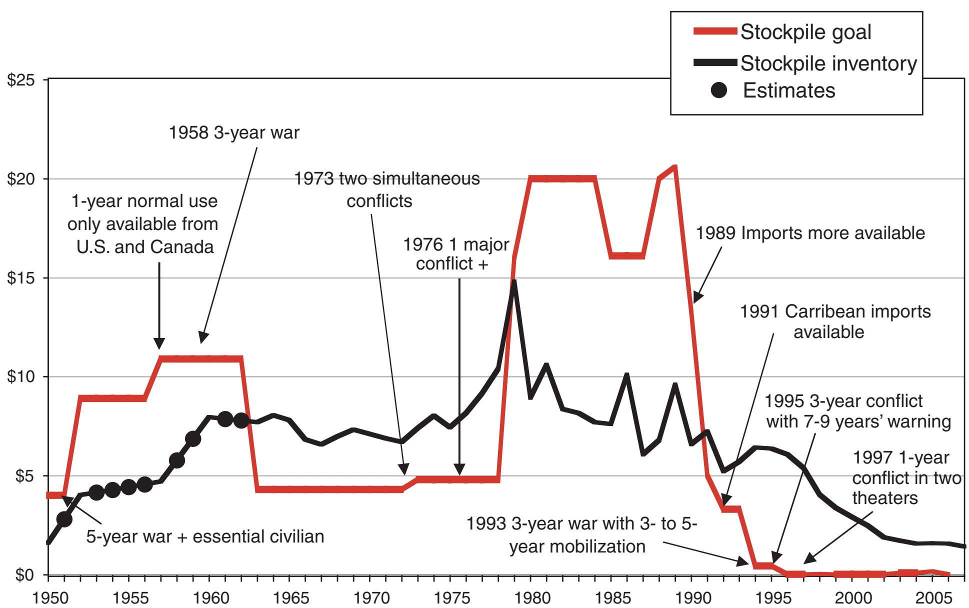

FIGURE 6-2 Stockpile goals and inventory (billion dollars). SOURCE: Data from U.S. census reports and presentations to the committee.

used, the current model-based process to set materials requirements appears to be robust and well developed and to properly investigate a broad range of scenarios that generate materials requirements. However, the committee is concerned that the econometric models lack the specificity to identify actual military materials needs.

The committee is struck by the lack of coordination across the DoD and the military services to identify specific individual and shared materials needs. The IDA modeling to estimate stockpile requirements is done on the basis of economic models and not on specific DoD requirements. There may be specific high-priority needs for materials that are not being addressed owing to a lack of information on material usage. Indeed the fact that recent requirements for mica and quartz came from a process other than the modeling just underlines the weakness of the outcomes of a modeling process no matter how robust it is. These two materials requirements came not from the requirements model but from off-line policy considerations.

It appears that DoD itself has been concerned about such specific materials requirements for some time. The committee notes that a DoD instruction, DoDI 4210.8, issued on April 15, 1972, states as follows: DoD Components will obtain Bills of Materials from contractors for all major Class A items of procurement, and will keep their Bill of Materials files current. Class A items were defined as "usually specially-designed military end items or components" containing any controlled materials. Controlled materials were defined as certain shapes and forms of steel, copper, aluminum, and nickel alloys. To the extent that DoD is concerned about certain materials in the future, the instruction could be updated to obtain information on those materials. That information could be integrated into a summary of critical materials needs and the results used to determine potential materials problems during peacetime as well as during a national emergency. It is not clear that this instruction has ever been implemented.

Conclusions on the Operational Framework for the Stockpile

The NDS operates within a defined legislative framework. However, the committee found a number of instances in which this operational framework could do with some clarification.

Estimating Stockpile Requirements

The first instance needing clarification arose from the committee's comparison of the results of the requirements analysis and what is reported by DoD as requirements in its biennial report to Congress. In preparing the report, the Secretary of Defense is directed by law to use the following guidance: "The stockpile requirements shall be based on those strategic and critical materials necessary for the United States to replenish or replace, within three years of the end of the military conflict scenario required under subsection (b), all munitions, combat support items, and weapons systems that would be required after such a military conflict."[7] However, the DoD requirements for beryllium HPP, mica, and quartz in recent reports came not from an analytical analysis but from an interagency process considering the supply chain needs for those materials. While this process is not inconsistent with the stated purpose of the law, which is "to provide for the acquisition and retention of stocks of certain strategic and critical materials and to encourage the conservation and development of sources of such materials within the United States and thereby to decrease and to preclude, when possible, a dangerous and costly dependence by the United States upon foreign sources for supplies of such materials in times of national emergency,"[8] from a practical standpoint, the direction in law on how the DoD is to determine requirements for the report may be overly restrictive and may not reflect actual national security needs.

Restrictions on DoD Authority to Take Action Without Congressional Approval

The second instance needing clarification concerns the limitation on operation of the stockpile, by which the Congress must approve all acquisitions and disposals in nonemergency periods unless the action is directed by the President of the United States. The committee notes that requirement may keep the NDS from taking advantage of short-term changes in market prices and demand when disposing of material. If there were a requirement to acquire a material, the congressional approval process could slow down the acquisition even if the stockpile Transaction Fund had sufficient excess cash to carry it out.

Foreign Sources

The third matter needing clarification is foreign sources. As the U.S. economy has become more globalized, defense production has also become more globalized. DoD defines a strategic material as "material required for essential uses in a war emergency, the procurement of which in adequate quantity, quality, or time, is sufficiently uncertain, for any reason, to require prior provision of the supply thereof." This would cover all materials regardless of where they are obtained. In contrast, the legislation governing the NDS defines strategic and critical materials in a more restrictive way in that such materials "are (B) are not found or produced in the United States in sufficient quantities to meet such need." As pointed out in

[7]50 *U.S. Code* 98, Section 2(b)
[8]50 *U.S. Code* 98, Section 2(c)

previous chapters, most materials are not found or produced in the United States in sufficient quantities to meet all U.S. needs. The purpose of the stockpile, as stated in the law, is "to decrease and to preclude, when possible, a dangerous and costly dependence by the United States upon foreign sources for supplies of such materials in times of national emergency." Given the fact that defense production has become more globalized in recent years, some clarification in defining strategic and critical materials that takes into account current supply chain operations, would help to identify the materials that should be considered for stockpiling.

The committee concludes as follows:

- The list of specific materials that have been considered for the stockpile over the last 20 years or so has largely been static. It is narrow as well, especially in light of emerging and future materials needs.
- There have been significant time lags between changes in military planning and their reflection in the scenarios used for modeling stockpile requirements; between DoD identifying its stockpile requirements and Congress legislating the stockpile's goals; and between legislating the goals and achieving the inventory levels in the NDS.
- The goal materials that are being held and are not for sale by the NDS were not identified by detailed econometric modeling methods and are not based on changes in military scenarios.
- The NDS goals have not changed in response to changes in military planning scenarios.

Summary Remarks

The committee believes that the key to any analysis of the NDS operation today is that in the 1990s the materials requirements reported to Congress shifted such that they now equal zero, except for three items, bringing into question the need for a stockpile. The committee considers the main cause of this shift was the interpretation of the "dangerous and costly dependence" clause of the law governing the NDS. The committee heard from DoD that in the 1990s, it believed the more globalized supply for defense systems, components, and raw materials (as opposed to reliance on an entirely domestic market) would mitigate the risk of dangerous and costly dependence, especially when there was a stated willingness to pay any price required for defense-related raw materials. Such a policy position seemed to be justified as raw materials became more available in the 1990s. However, the committee became convinced during the course of this study that (1) the increasing demand from large developing economies, (2) the recent decline in the capacity of U.S. industry to supply and process raw materials for defense systems, and (3) the continuing increase in U.S. dependency on foreign sources for materials call for a fresh assessment of the risk and a new policy response. The committee's analysis identifies a potential today for disruption in the supply of materials and minerals critical to the U.S. military that economic modeling might not identify. There is the possibility, therefore, that the risk of a more dangerous and costly dependence is not being identified by the current system. It seems that the law, written so long ago, requires updating to better define what a dangerous and costly dependence might be in the twenty-first century. A new system needs to be established to assure the supply of materials critical to defense systems.

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Appendixes

A

Stockpile History

The idea of maintaining stocks of materials is not something recent. Ever since ancient times maintaining adequate supplies of important materials has been known. In the first book of the Old Testament, Genesis Chapter 41, we are told how nearly 4,000 years ago Egypt built a stockpile of food equal to two years of normal consumption. We all keep stocks or inventories of items (milk, bread, and so on) as a form of insurance for use in an emergency. Today's National Defense Stockpile (NDS) has a long history. It is marked by numerous public laws, debates among military and civilian agencies, changing requirements, and changing political views.

By 1917 it was noted that the United States was

> deficient in certain minerals of great importance, particularly in war time . . . The remedy may mean . . . the accumulation of a reserve supply, either by government or private companies. (Morgan, 1949)

> The many supply shortages of strategic materials encountered in World War I caused the War Industries Board to recommend that future materials problems should be anticipated and ameliorating actions taken. (Morgan, 1993)

> In 1922 the Army and Navy Munitions Board was established in the War Department to plan for industrial mobilization and procurement of munitions and supplies. The pre-World War II list of important materials was divided into two groups: 14 strategic materials essential to the national defense the supply of which in war must be based entirely or in substantial part on sources outside the United States and 15 critical materials essential to the national defense procurement of which in war would be less difficult (for example, more readily available domestically) than the strategic materials. (Morgan, 1949)

FROM 1938 THROUGH WORLD WAR II

The first activity to develop an inventory of strategic and critical materials for military use was authorized in the Naval Appropriations Act of 1938, which also provided funds to buy strategic items. But today's NDS had its beginning with the passage of the 1939 Strategic Materials Act, which authorized $100 million for the Secretaries of War and the Navy acting jointly with the Secretary of the Interior and in conjunction with the Army and Navy Munitions Board to purchase strategic raw materials for a stockpile. The Army and Navy Munitions Board had developed a list of 42 strategic and critical materials needed for wartime production. The list was based on the threatened loss of vital imports as a consequence of Japanese conquests in Asia and the possibility of war in Europe (Snyder, 1966). By May 1940, small quantities of certain materials—such as chromite, manganese, rubber, and tin—were procured under the Strategic Materials Act. By October 1940, both the Army and Navy Munitions Board and the National Defense Advisory Commission, a Presidential advisory group, had recommended specific quantities of strategic minerals for stockpiling, many of which were the same as on the earlier list. Unfortunately, the acquisition of these materials was not completed before the beginning of the war, because only $70 million of the $100 million had been appropriated by Congress and only $54 million worth of materials had been acquired.[1]

Throughout World War II, the United States relied mainly on its strong industrial base for processing and manufacturing to meet national defense needs. All segments of the industry were fully mobilized in a short time to manufacture the goods and products needed to win the war. To support this effort, numerous materials were imported in large quantities—such as ferroalloys, manganese, tin, and natural rubber. Several federal agencies—including the Reconstruction Finance Corporation and the War Production Board, which was formed in January 1942—were responsible for importing these materials, as well as arranging for the building up of government-owned reserves or stockpiles of strategic and critical materials. Major expansions of the domestic supply of materials were financed by the federal government, most notably the supply of aluminum and synthetic rubber. Of the 15 materials in the stockpile during World War II, only 3 were from domestic sources, while the rest were from foreign sources (War Department and Navy Department, 1947). Between 1942 and 1944, 6 materials in the national stockpile inventory were released for military needs, and a seventh material under contract but not yet in the stockpile was redirected, all by Executive Order of the President (War Department and Navy Department, 1947).

[1]House of Representatives, Readiness Subcommittee of the House Armed Services Committee. 1994. Prepared Statement of Alfred R. Greenwood, Congressional Research Service before the Readiness Subcommittee on Issues Relating to the National Defense Stockpile. March 8.

POST-WORLD WAR II TO 1958

The first significant post-World War II congressional action pertaining to stockpiling was passage of the Strategic and Critical Materials Stock Piling Act of 1946 (Public Law 520-79). Consideration of this legislation began well before the end of the war and was contentious at times. The struggle centered on two broad subjects: the purposes which stockpile policy was to serve; and the roles and procedures for making policy, which, in effect, would determine the degree of influence for each of the interested agencies, and the allocation of power between the Executive Branch and Congress (Snyder, 1966). Some parties wanted to eliminate the Buy-American clause; others focused on only military requirements. Still others wanted civilian, international trade, and economic needs considered. The questions of which agency should have control, which should develop requirements, and which should set policy were all debated.

The resulting legislation (Public Law 520-79) was a compromise and not a completely new law: It was an amendment to the Strategic Materials Act 1939. Section 2 provided for the Secretaries of War, Navy, and Interior, "acting jointly through the agency of the Army and Navy Munitions Board, [to] be authorized and directed to determine . . . which materials are strategic and critical . . . and to determine . . . the quality and quantity of such materials which shall be stockpiled" in cooperation with the Secretaries of State, Treasury, Agriculture, and Commerce. Other actions were authorized in the 1946 law: the appointment "to the fullest extent practicable" of industry advisory committees; the application of the Buy American Act of 1933 to purchases; the storage of materials on military and naval reservations; the refining or processing of required materials; the rotation of stockpiled materials to prevent deterioration; the disposal of stockpiled materials after 6 months notice in the Federal Register and notice to Congress—no materials were to be disposed of without congressional approval except for reasons of their obsolescence; and the transfer into the stockpile at no cost of stocks held by other government agencies during the war. The new law also required Presidential authorization for the release of materials. Materials were to be purchased by the Procurement Division of the Treasury Department, which subsequently became the Bureau of Federal Supply.

The National Security Act of 1947 created a civilian mobilization agency, the National Security Resources Board, to advise the President. Its functions included "the coordination of military, civilian, and industrial mobilization including the policies establishing adequate reserves of strategic and critical materials and for the conservation of these reserves" (Snyder, 1966). This new board had the lead in stockpile policy. The Munitions Board, which was formed from the Army and Navy Munitions Board, had responsibility for evaluating military as well as civilian needs. It was aided by a civilian interagency advisory team initially called the

Strategic Materials Committee and later the Interdepartmental Stockpile Committee. This committee had knowledgeable representatives from the Departments of State, Treasury, Interior, Commerce, and Agriculture that coordinated with the Munitions Board in developing stockpile goals. The Munitions Board and the Interdepartmental Stockpile Committee were advised by additional interdepartmental commodity committees that provided data on production, supply, and requirements for specific materials (Snyder, 1966).

By 1948 the Munitions Board had developed a list of 51 required strategic and critical material groups estimated to have a value of $2.1 billion. By 1950 the actual stockpile inventory had reached a market value of $1.6 billion, and an additional $500 million worth of materials were on order (Snyder, 1966). Also by then, the number of required strategic and critical materials had expanded to 54 groups, representing 75 specific commodities, with an estimated objective value of $4.0 billion (Snyder, 1966). These requirements were identified based on the updated planning requirements for a 5-year conventional war and would also provide materials for essential civilian use. With the outbreak of the Korean War, Congress quickly appropriated $2.9 billion in a 6-month period for stockpiling of materials. Also, the value of the requirements jumped to $8.9 billion (Snyder, 1966).

Materials were to be stored at secure locations close to points of use and transportation. Military and government depots were preferred primarily for reasons of security and economics. In January 1948, 70 military depots, 10 commercial warehouses, and 3 stand-by defense plants were being used as storage sites. By August 1953 the stockpile was stored at 318 locations consisting of 71 military depots, 9 GSA depots, 4 government-owned vaults, 6 commercial vaults, 165 commercial warehouses, 34 commercial tank-farms, 7 open-air commercial sites, 4 open-air government sites, and 18 industrial plants (Snyder, 1966).

In 1949 the Bureau of Federal Supply had been transferred from the Treasury Department to the newly created GSA. With the Korean War in 1950, the stockpile program had expanded to become a separate activity in the Emergency Procurement Service of the GSA (it became the Defense Materials Service in September 1956). The Defense Production Act of 1950 authorized the government to divert resources to military and essential programs, including stockpiling, and to expand production of needed materials. By the end of 1950, President Truman declared a national emergency and created the Office of Defense Mobilization and Defense Production Administration. Many of the National Security Resources Board's responsibilities relating to stockpiling were transferred to these new agencies (Snyder, 1966).

During the Korean War, which lasted until 1953, the government released, under Presidential Order, "about $60 million worth of materials, primarily aluminum and copper" from the stockpile (Office of Defense Mobilization, 1956). As many as eight materials were released between 1951 and 1953 for defense purposes under

12 Presidential Orders (Gutchess, 1969). In addition, large quantities of materials on order to the stockpile were diverted to meet industry needs. The Munitions Board thought that the Defense Production Administration released too much material to civilian use rather than stockpiling it for defense (Snyder, 1966). By 1953 the mobilization controls and allocations were removed, and stockpiling of materials resumed. Between December 1949 and December 1952, the inventory value went from $1.15 billion to $4.02 billion; total stockpile objectives went from $3.77 billion to $7.49 billion in the same period. (Munitions Board, 1950, 1953) Twice under a Presidential Order in 1952 and once again under such an order in 1956, mercury was released, at no cost, for use in the atomic weapons program (Gutchess, 1969; Kulig, 1992).

President Eisenhower consolidated mobilization functions within the government in 1953. The Office of Defense Mobilization was reorganized and took over the duties of the Defense Production Administration and the National Security Resources Board, both of which were abolished. The Munitions Board transferred the stockpiling program to this new agency, thereby putting the stockpiling activity under civilian control, except for determining the military requirements, the responsibility for which was transferred to the new Assistant Secretary of Defense for Supply and Logistics (Snyder, 1966). The GSA continued to purchase and manage stockpile materials and facilities. During the mid-1950s stockpiling continued, with materials being added from transfers of materials acquired under the Defense Production Act programs and the Department of Agriculture's program for the sale of surplus food to foreign countries, which was paid for in commodities. Determining the stockpile requirements had become more political during this period. Requirements were now developed based on new criteria, 1-year's normal use and no reliance on imports for the materials in the stockpile from anywhere beside Canada and Mexico. The Office of Defense Mobilization in 1956 reported materials requirements with a value of $10.9 billion; $6.4 billion of this was said to be the minimum required, and $4.7 billion worth of those materials were in the stockpile's inventory (Office of Defense Mobilization, 1956).

COLD WAR YEARS

During the mid-1950s, the military planners began to examine new scenarios for wars of short duration based on a nuclear conflict, impacting the concept of industrial mobilization and industry's need for materials. These strategies for the Cold War would greatly reduce the quantities of materials needed in the stockpile in years to come. A revised plan was developed in 1958 based on a 3-year war instead of a 5-year war. Excess materials could disposed of only if they did not disrupt U.S. domestic markets or affect foreign relations. Outstanding contracts were terminated or reduced during this time. Of the 75 materials in the government stockpiles, all but 12 were now in excess (Snyder, 1966). In 1959 an advisory committee of the Departments of Commerce, State, Interior, Agriculture, and Defense was established to review disposal plans. Disposals from the national strategic Stockpile and Defense Production Act Stockpile progressed slowly between "1954 and 1964 because of legal restrictions, cumbersome administrative procedures, and strong resistance from both domestic and foreign interests" (Snyder, 1966).

In 1962 President Kennedy announced that he was "astonished to find that the stockpiling program had accumulated $7.7 billion worth of materials, an amount nearly $3.4 billion greater than estimated wartime needs" (Snyder, 1966). The Executive Stockpile Committee under the Director of the Office of Emergency Planning, Executive Office of the President, was created to examine the disposal of strategic and critical materials. A congressional investigation held in 1962 and 1963 featured open hearings to examine the operations of the stockpile. The Interdepartmental Disposal Committee was established by the Director of the Office of Emergency Planning in 1963 to develop long-range disposal plans for materials no longer required (Office of Emergency Planning, 1965). By the end of 1965 disposal sales of stockpile materials had reached $1.6 billion (Office of Emergency Planning, 1966).

Interestingly, at the same time, a worldwide shortage of cadmium had developed by 1962; domestic users were forced to curtail production, including production for defense use. The Office of Emergency Planning, with Presidential approval, authorized the GSA to sell 2 million pounds of cadmium from the national stockpile. Congress waived the 6-month waiting period and authorized immediate disposal of the cadmium. The 2 million pounds were sold in four batches with some cadmiuim set aside for defense rated orders, small businesses, domestic consumers, and unrestricted consumers (Office of Emergency Planning, 1963). Also because of several sizable supply shortages in 1964, the Congress authorized emergency sales of antimony, lead, and zinc. In addition the President approved the release of copper from the Defense Production Act inventory in the stockpile in 1964 to relieve industry hardship cases (Office of Emergency Planning, 1965). Again in 1965, the President authorized copper from the national stockpile to be released "in the interest of common defense" (Office of Emergency Planning, 1966) because of a continuing worldwide shortage. Thus it can be said that the national stockpile materials served as a economic stabilizer during this period.

The Materials Reserve and Stockpile Act of 1965 directed that the national stockpile, the supplemental stockpile, including the Commodity Credit Corporation stockpile, and the Defense Production Act inventory be combined into one National Stockpile and that a long-range disposal plan be developed to reduce the inventory of excess materials. (The original national stockpile has been established under the Strategic Materials Act of 1939, and by September 1964, it had 89 strategic and critical materials with a market value of $6.0 billion. The Department of Agriculture's supplemental stockpile and the Commodity Credit Corporation stockpile were based on materials acquired by barter under the Agricultural Trade Development and Assistance Act of 1954; by September 1964, these held 50 materials with a market value of $1.3 billion. The Defense Production Act of 1950 had formed its own inventory under their industry expansion programs; by September 1964, it contained 22 materials with a market value of nearly $0.9 billion. The National Stockpile would be managed as one stockpile to hold all the required strategic and critical materials.)

In February 1966, the President authorized the release of quinine sulfate from the National Stockpile. The material was needed for use in Vietnam to combat a strain of malaria that resisted the synthetic drug being used. Also in 1966, the President authorized two additional releases of copper "for purposes of the common defense." In 1969, nickel strikes against the two major world producers of primary nickel drastically cut nickel availability, and the U.S. defense industry began to suffer. In December the President ordered the release of nickel for use in defense production. This stockpile release was in the form of a loan rather than a sale (Office of Emergency Planning, 1970) but was later changed to a sale since the requirement's quantity was reduced and the material did not have to be replenished.

A reevaluation of the stockpile by the National Security Council was completed by 1973. This was the basis for developing new goals or requirements for each material. Three conditions were set for the scenarios used to develop the materials requirements: (1) materials would be used only for defense purposes; (2) the analysis would include simultaneous multitheater (Europe and Asia) conflicts; and (3) imports of supplies would be available for all years of the national emergency.

By the end of FY1974, $2.05 billion worth of materials had been disposed of (GSA, 1979). In 1973 the Office of Emergency Planning was abolished and its stockpile planning and policy functions were transferred to the GSA.

In 1976 the President issued new stockpile policy guidance. The National Stockpile would support defense requirements during a major war over a 3-year period, operate on the assumption of full-scale industrial mobilization and increased materials demands, provide for a wide range of civilian economic needs to ensure a healthy economy, and develop the Annual Materials Plan to include provision for any acquisition or disposal of excess materials.

The National Stockpile program was changed again in 1979 by the Strategic and Critical Materials Stockpiling Revision Act; this was the second major revision of the original 1939 Act. Stockpile administration and policy functions were transferred to the newly created Federal Emergency Management Agency (FEMA) from the GSA. The management of storage, maintenance, upgrades, purchases, and sales remained with the GSA. In addition, the National Defense Stockpile Transaction

Fund was established in the Treasury Department for money received from sales. A 3-year duration for the conflict or national emergency period was reaffirmed.

In November 1979, the President released a portion of the chrysotile asbestos to the Department of Defense. The one operating mine, in Canada, had been depleted of reserves and the only other mine in the world, in Zimbabwe, was not producing (FEMA, 1980).

In 1981, President Reagan announced a "major purchase program for the National Defense Stockpile, saying that it was widely recognized that our nation is vulnerable to sudden shortages in basic raw materials that are necessary to our defense production base" (FEMA, 1981).

During the early 1980s, the U.S. metallic minerals production industry was at best stagnant and often in decline. The world economy was in a recession that impacted the production of minerals. U.S. metal mines and processors closed down operations. In 1982 the GSA initiated a presidentially directed long-term program to upgrade chromite and manganese ores to high-carbon ferrochromium and high-carbon ferromanganese. This program would help sustain a U.S. ferroalloy furnace and processing capability vital for the national defense industry. The program was paid for with excess stockpile materials that were authorized for disposal (FEMA, 1985). Between 1984 and 1994, nearly 1.4 million tons of chromite ore and 1.0 million tons of manganese ore were upgraded to ferroalloys (DoD, 1994).

The selling of excess materials and the purchasing of required materials, using funds from the Transaction Fund, continued from 1981 through 1985, when the GSA suspended sales temporarily because the Transaction Fund had reached the mandated $250 million limit. Disposals were continued, and the funds were used to support the presidentially directed ferroalloy upgrading program and the transfer of silver to the Department of the Treasury for use in minting Liberty coins (FEMA, 1986). Limited purchases, disposals, upgrades, and transfers of materials continued to 1988. From August 1979 through September 1988, total net receipts of nearly $1.2 billion had been credited to the National Defense Stockpile Transaction Fund; the available balance totaled $505 million, while the remaining amount had been approved by Congress to purchase goal materials and for research grants (DoD, 1989).

The Cold War was drawing to a close by the late 1980s with the demise of the nuclear military threat from the Soviet Union. At that time, military planners were reevaluating the conflict scenarios to be used for DoD budget planning. This would lead to major changes for the armed services and the stockpile in years to come.

POST-1988—A PARADIGM CHANGE

In February 1988, Executive Order 12626 designated the Secretary of Defense to be the National Defense Stockpile manager. He then delegated the managerial functions to the Assistant Secretary of Defense for Production and Logistics, supervised by the Under Secretary for Acquisition. The operational activities were delegated to the Director of the Defense Logistics Agency. The Defense National Stockpile Center was established as a field activity within the Defense Logistics Agency to manage the operations of the stockpile program (DoD, 1988). FEMA and the GSA transferred all funds, personnel, property, and records of the National Stockpile to DoD. The civilian agencies were now out of the stockpiling business except for being represented on the advisory committees. Executive Order 12626 also directed that the Secretary of Defense (stockpile manager) must consult with heads of other agencies when performing stockpiling functions (for example, disposals).

DoD planning guidance began to change in 1989. The Cold War military conflict, as in the past, was still the scenario, but the reliability of foreign countries as sources for materials improved. By 1991, Caribbean Basin suppliers were considered reliable, and other foreign country reliabilities were modified. By 1992 the 3-year global war scenario was being questioned, the military force structure was reduced, and foreign countries were considered to be more reliable as suppliers. A highly mobile armed forces that would "come as you are" was the direction of the future military. In 1995, the scenario in use was a 3-year conflict with a 7- to 9-year warning period, which included a short military conflict followed by a 2-year stalemate, followed by another short military conflict. Most foreign suppliers were considered to be reliable, and platinum group metals for automotive catalytic converters were taken off the requirements list. In 1997, the scenario used to develop the stockpile requirements was the same as for other DoD planning: a 1-year conflict involving two overlapping major theater wars (Halpern, 2007). These planning scenarios were used in the biennial Defense National Stockpile Requirements Report to Congress. Based on this report, requirements for strategic and critical materials had been reduced to nearly zero by 2003.

In April 1992, Congress held a hearing on DoD's 1992 Stockpile Requirements Report of 1992. The Assistant Secretary of Defense said that because of the changing military scenario, requirements had been reduced for stockpiled materials, to $3.3 billion (House of Representatives, 1992). Congress responded to DoD's recommendations by authorizing the disposal of large quantities of 44 NDS materials in the National Defense Authorization Act for FY1993 (DoD, 1993).

From FY1988 through FY1992, the stockpile had already disposed of $435 million worth of materials (DoD, 1993, 1994). As of September 1992, the NDS inventory held 84 individual materials with a total value of $7.1 billion. Nearly all acquisitions and upgrades had stopped by FY1994, with very small amounts continuing until FY1997, when they were completed (DoD, 1998).

Section 2 of the Strategic and Critical Materials Stockpiling Act, as amended by the National Defense Authorization Act for FY1993, stated that "the purpose of the NDS is to serve the interest of national defense only. The NDS is not be used for economic or budgetary purposes" (DoD, 1993). Congress would legislate acquisitions and disposals (Section 5). Section 6 specifies that "efforts shall be made in the acquisition and disposal of such materials to avoid undue disruption of the usual markets of producers, processors, and consumers of such materials and to protect the United States against avoidable loss." Section 10 established the Market Impact Committee, composed of representatives from the Departments of Defense, State, Commerce, Interior, Agriculture, Energy, and the Treasury, and from FEMA. The committee would advise the National Stockpile Manager on the projected domestic and foreign economic effects of all acquisitions and disposals of stockpiled materials included in the Annual Materials Plan that is to be submitted to Congress each year (DoD, 1993). The Annual Materials Plan specifies the maximum quantity of each commodity that may be sold or bought by the DoD in a given fiscal year.

Under the National Defense Authorization Act of 1996, the DNSC was directed to transfer 250 tons of titanium sponge each year from FY1996 through FY2003 to the Army's Tank and Automotive Command. This material was used to make lighter weight armor for the main battle tank (DoD, 2004).

From FY1993 through FY2005, $5.9 billion worth of materials was sold (DoD, 2006). Since the main sales program began in FY1993, Congress has earmarked part of the proceeds from the sale of DNS materials for particular revenue goals. In fact the sale of certain materials was assigned to fund specific programs. By the end of FY2006, a total of nearly $3.9 billion had gone to support specific accounts. From FY1993 through FY2001, $1.65 billion had been transferred to the military operation and maintenance readiness accounts, in equal amounts to the Army, Navy, and Air Force, from the Stockpile Principle Sales Program Transaction Fund.

A long-term program was begun in FY1997 for the sale of 11 commodities to offset costs of the Foreign Military Sales Program; by FY2006, $633 million had been placed in the Foreign Military Sales Program Transaction Fund. Starting in FY1999, another funding program was started for 27 commodities; the Health and Human Services and Treasury General Fund Program Account was authorized to transfer funds to the Department of Health and Human Services for the Federal Hospital Insurance Trust Fund and Federal Supplementary Medical Trust Fund; through FY2003 this fund received $92 million. A long-term program was started in FY2000 for revenues to reclaim certain radio frequencies that are reserved for DoD but were to be surrendered for civilian use and to fund various military personnel benefit programs; $426 million had been put into the Spectrum Sales Program Transaction Fund by FY2006. The World War II Memorial and MILPERS Benefit Program Transaction Fund were authorized to sell one commodity; in FY2001 and FY2002, $6 million was transferred to the American Battle Monument Commission for the World War II Memorial; the remainder was deposited into the General Fund of the Treasury for military personnel benefits. Nearly $1.1 billion has been transferred to the General Fund of the Treasury portion for all the specific sales programs (DNSC, 2007).

Owing to the large reductions in the number and quantities of materials, DNSC has been able to sharply reduce the number of facilities warehousing materials. Under the current plan, by the end FY2007, DNSC will have three operating, consolidated storage locations and a total workforce of 65.

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B

U.S. Defense Strategy

U.S. defense planning historically has been based on an enumeration of likely warfighting scenarios. Thus, in the early days of the Cold War, defense planners based their risk analyses on the need to be able to respond to two and one-half conflicts at one time—that is, war with the Soviet Union in Europe, possible conflict with Communist China in Asia, and a "half war" with another regional state—Vietnam, as it turned out. This additive regional conflict approach was first proposed by Secretary of Defense McNamara during the Johnson administration. For the most part, successive administrations would maintain this conflict-counting strategy[1]: President Nixon's strategy presumed the need to respond to one and one-half conflicts simultaneously, for example, while President Clinton's strategy evolved into what became known as "two regional conflicts nearly simultaneously." The two distinct periods that substantially stray from this general approach were the years following the end of the Cold War and the Bush administration's post-9/11 force planning strategy.

RESPONDING TO THE END OF THE COLD WAR: THE BASE FORCE (1989-1992)

With the fall of the Berlin Wall came the recognition that U.S. defense planning, strategizing, and force structure would need fundamental realignment. Both the initial and revised approaches, conceived largely by General Powell during the first

[1] Fred Kaplan, "The doctrine gap: Reality vs. the Pentagon's new strategy," *Slate* (July 6, 2005). Available online at http://www.slate.com/id/2122010/

Bush administration, concentrated on the need to address a regional or global conflict while maintaining a minimal force and preserving a hedge capacity to rebuild defenses for global warfare in the event of a resurgent superpower rivalry.[2] As such, the defense strategy outlined in the 1992 National Military Strategy (NMS) called for a new, four-pronged approach[3]: strategic deterrence and defense, forward presence (a smaller force than conceived under the earlier forward defense strategy), crisis response (given the geographic uncertainty surrounding future conflicts), and reconstitution.

The last two prongs of the strategy were linked in that in times of crisis, including the potential for a reconstituted Soviet threat, they would explicitly allow returning to Cold-War-era force levels and capabilities if necessary. This was deemed a vital part of the defense strategy given domestic (i.e., congressional) interest at the time in cutting defense spending in order to reap a "peace dividend," a goal that Pentagon officials feared might cut too deep into military readiness.[4] As explained in the NMS (1992, pp. 7-8 and 24-25, italics added), the stockpiling of critical materials was an integral part of the plan:

> This 'reconstitution' capability is intended to deter such a power from militarizing and, if deterrence fails, to provide a global warfighting capability. Reconstitution involves forming, training, and fielding new fighting units. This includes initially drawing on cadre-type units and laid-up military assets; mobilizing previously trained or new manpower; and activating the industrial base on a large scale. Reconstitution also involves maintaining technology, doctrine, training, experienced military personnel, and innovation necessary to train the competitive edge in decisive areas of potential military competition. . . .
>
> Preserving the potential for expansion of air, ground, and maritime forces will require extraordinary foresight and political courage to lay away infrastructure, *stockpile critical materials*, protect the defense industrial base, sustain a cadre of quality leaders, and invest in basic science and high-payoff technologies. Reconstitution also requires important decisions based on early strategic warning.
>
> A key element in responding to this challenge is Graduated Mobilization Response. This national process integrates actions to increase our emergency preparedness posture in response to warning of crisis. These actions are designed to mitigate the impact of a crisis and to reduce significantly the lead time associated with responding to a full scale national security emergency.

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[2]Eric V. Larson, David T. Orletsky, and Kristin J. Leuschner, *Defense Planning in a Decade of Change: Lessons from the Base Force, Bottom-Up Review, and Quadrennial Defense Review* (Santa Monica, Calif.: RAND Corporation, 2001); Lorna S. Jaffe, *The Development of the Base Force 1989-1992* (Joint History Office, Office of the Chairman of the Joint Chiefs of Staff, July 1993). Available online at http://www.dtic.mil/doctrine/jel/history/baseforc.pdf.

[3]Chairman of the Joint Chiefs of Staff, *National Military Strategy* (Washington, D.C.: Defense Technical Information Center, 1992). Available at http://stinet.dtic.mil/cgi-bin/GetTRDoc?AD=ADA338837&Location=U2&doc=GetTRDoc.pdf.

[4]Jaffe, op. cit.

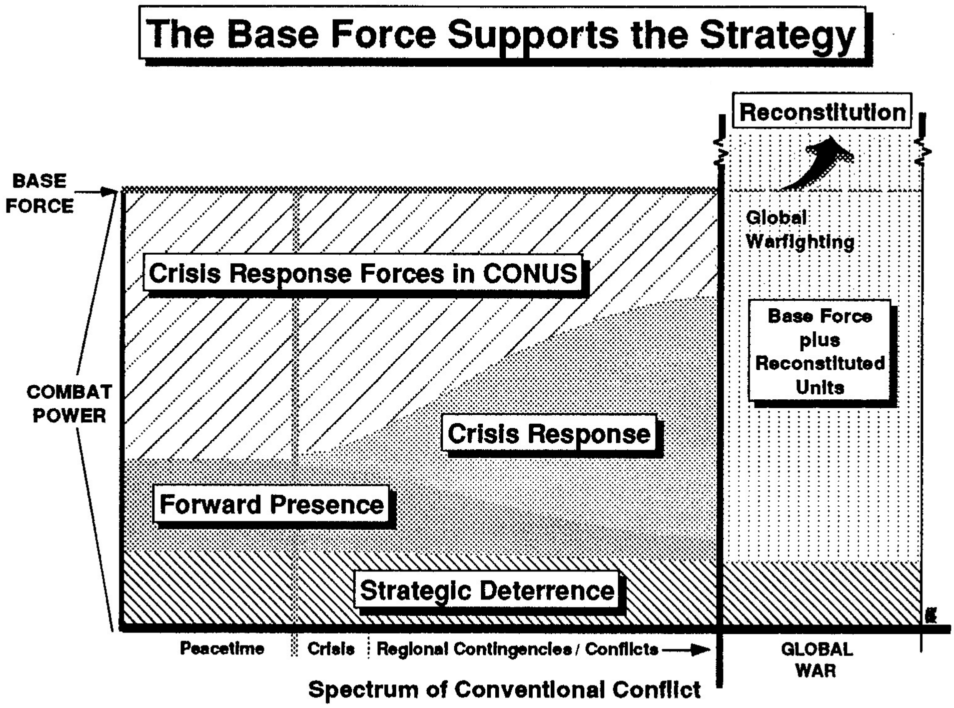

FIGURE B-1 Schematic depicting the expected spectrum of conflict. SOURCE: NMS (1992).

The schematic depicting the expected spectrum of conflict is shown as Figure B-1.

In addition to explicitly including a reconstitution phase as part of the defense strategy, the Base Force was distinct in that it was "determined principally by the need to protect and promote U.S. interests in regions vital to the United States . . ." rather than by sheer military capability to fight a chosen number of expected conflicts as earlier and subsequent defense plans have been.[5] But the plan would be overcome by events. By the time the Base Force could be implemented, U.S. forces had conducted regime change in Panama, the Soviet Union and its hold on Eastern Europe had collapsed, and a new front had opened in the Middle East with Saddam Hussein's invasion of Kuwait.

[5]Larson et al., op. cit., p. 12, fn 28: "Although it was not designed on this basis, the Base Force would, however, be assessed by the Joint Chiefs of Staff in terms of its ability to fight one or more MRCs."

THE BOTTOM-UP REVIEW—1993-1997

The Clinton administration would ultimately maintain the regional focus adopted in the Base Force construct but revert to sizing the force based on the capability needed to win a select number of geographic conflicts. To determine the appropriate strategy, capabilities, and force structure in the wake of the Cold War and the successful but conventional Gulf War I, Secretary of Defense Aspin conducted a fundamental bottom-up review (BUR). The end result of this review was initially a win-hold-win strategy involving two major regional conflicts (MRCs). This was soon adjusted to a somewhat more robust strategy, winning two nearly simultaneous MRCs (for instance, North Korea and Iraq).[6] Like its predecessor, the BUR contained an explicit hedge approach:

> . . . sizing our forces for two major regional conflicts provides a hedge against the possibility tha]t a future adversary might one day confront us with a larger-than-expected threat, and then turn out, through doctrinal or technological innovation, to be more capable than we expect, or [to] enlist the assistance of other nations to form a coalition against our interests.

There was no further mention, however, of the need to maintain a reconstituting capability. Rather, with the advent of the new doctrine Revolution in Military Affairs (RMA),[7] which was based on enhanced information and communications technologies, U.S. defense planning and sourcing began to assume an explicitly international character. Moreover, as part of an expanded forward presence concept, the strategy required prepositioning of military equipment and supplies to facilitate a rapid American military response should a crisis occur.

1997 QDR—1997-2001

Broad dissatisfaction with the two-MRC construct led to a fresh review of U.S. defense strategy and posture 4 years later. The *1997 Quadrennial Defense Review (QDR)* adopted a longer-term outlook, assessing security and defense needs through 2015. The result was a strategy designed to shape the international security environment in ways favorable to U.S. interests, respond to the full spectrum of crises when directed, and prepare now to meet the challenges of an uncertain future.[8]

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[6]Les Aspin, *Report on the Bottom-Up Review,* OSD, DoD (October 1993). Available at http://www.fas.org/man/docs/bur/index.html.

[7]For further information see Steven Metz and James Kievit, *Strategy and the Revolution in Military Affairs: From Theory to Policy* (1995). Available at http://www.au.af.mil/au/awc/awcgate/ssi/stratrma.pdf. Accessed December 2007.

[8]Office of the Secretary of Defense, *1997 Quadrennial Defense Review.* Available at http://www.fas.org/man/docs/qdr/.

Nonetheless, the force structure outlined to achieve these aims was familiar, with the two MRCs renamed "major theater wars" in overlapping time frames. Added to the two-MTW strategy was the need to also respond to smaller scale contingencies that might arise, such as conflicts in places like Bosnia or Kosovo. Additionally, building on the BUR's support for enhanced allied assistance and supply, the DoD continued to expand its case for needing a national defense industrial base with the ability to trade and source globally as an essential element of long-term U.S. national security.[9] However, Congress, a naturally more conservative group, never fully signed on to this need to trade globally in order to stay economically, technologically, and militarily far ahead of any and all future competitors. This conceptual divide persists today (as evidenced in the discrepancy between the law and practice governing the NDS) and is likely to play in any debate over the need to maintain the NDS.

2001 QDR—2001-2005 (Post-9/11)

On coming into office, Secretary of Defense Rumsfeld was intent on transforming the military as a means of implementing and making the RMA doctrine permanent across DoD. Yet, the need to respond to September 11-type attacks would also impact the approach adopted in the congressionally mandated the *2001 QDR*, which came out shortly thereafter and had to be hastily revised to further reflect homeland defense. The main innovation stemming from that the *QDR* was the adoption of a capabilities-based approach rather than a traditional threat-based approach. In other words, rather than focus on trying to anticipate and identify probable future threats (posed by state or nonstate actors) the capabilities-based approach is designed to assure a force structure ready to meet any threat regardless of its origin, geography, or timing. Accordingly, the defense strategy outlined in the *2001 QDR* focused on a new approach to dealing with a range of concerns, threats, and possible conflicts:

- Defend the United States;
- Deter aggression and coercion forward in critical regions;
- Swiftly defeat aggression in overlapping major conflicts while preserving for the President the option to call for a decisive victory in one of those

[9]For a comprehensive argument outlining DoD's interest in supporting a dual-use, globally sourced defense industrial base, see Defense Science Board, *Final Report of the Defense Science Board Task Force on Globalization and Security,* December 1999. Available at http://www.acq.osd.mil/dsb/reports/globalization.pdf.

conflicts, including the possibility of regime change or occupation [note: a modified version of the 2 MTW approach]; and

- Conduct a limited number of smaller-scale contingency operations.[10]

As this new force-planning structure evolved, it became known as the 1-4-2-1 strategy:

1 Defend the United States,
4 Deter forward in 4 critical regions (Europe, northeast Asia, east Asian littoral, southwest Asia),
2 Swiftly defeat two adversaries nearly simultaneously, and
1 Win one decisively—that is, potential regime change.[11]

The strategy also maintained the need to be able to respond to small-scale contingencies but gave more emphasis to a "force generation capacity" and a strategic forces reserve. This is the defense planning strategy that currently underlies the most recent IDA analysis for the NDS.

2006 QDR—2006-2010

The latest iteration of defense planning as outlined in the most recent QDR is a modified 1-4-2-1 approach, where the 4 now refers to the need to respond to a spectrum of challenges that are irregular, traditional, catastrophic, or disruptive, as depicted in Figure B-2.[12]

The present *QDR* expands on the fundamental strategy set out in the 2005 National Defense Strategy (NDSt). The 2005 NDSt, Secretary Rumsfeld's only published NDSt, is the source of this new quadrangular approach to dealing with

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[10]Office of the Secretary of Defense, *2001 Quadrennial Defense Review,* p. 17. Available at http://www.comw.org/qdr/qdr2001.pdf.

[11]The 1-4-2-1 construct is formally referenced in the 2004 National Military Strategy, a product of the Chairman of the Joint Chiefs of Staff in support of the National Security Strategy (a White House document) and implementing the 2005 National Defense Strategy (from OSD). IDA's analysis appends a "1" to the 1-4-2-1 construct, adding "1 smaller scale contingency." The 2005 NDS, however, states the need to also "conduct a limited number of lesser contingencies." See Office of the Chairman of the Joint Chiefs of Staff, *National Military Strategy of the United States of America 2004: A Strategy for Today; A Vision for Tomorrow* (March 2005) and Office of the Secretary of Defense, *National Defense Strategy of the United States of America* (March 2005), referred to hereinafter by the acronym NDSt to distinguish it from NDS.

[12]The 1-4-2-1 construct does not appear in the *QDR* document. However, as in the earlier QDR process, Pentagon officials use this shorthand to describe the present strategy. For the formal document (which was due in 2005 but was delayed), see Office of the Secretary of Defense, *2006 Quadrennial Defense Review.* Available online at http://www.defenselink.mil/qdr/report/Report20060203.pdf.

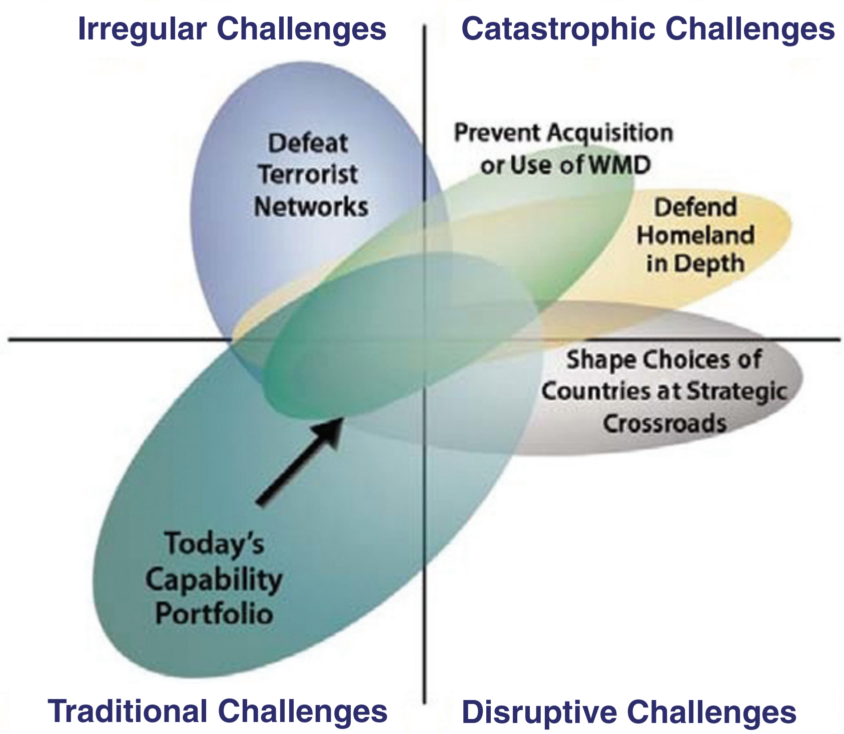

FIGURE B-2 2006 QDR responses to the spectrum of challenges. SOURCE: OSD (2006, p. 19).

security challenges old and new. Arguably two of the four types of challenges are most likely to impact the National Defense Stockpile (NDS): traditional challenges (nation-state adversaries) and disruptive challenges (revolutionary technology and associated military innovation). The remaining challenges—irregular (terrorist incidents) and catastrophic (use of weapons of mass destruction)—also hold the potential to impact the NDS but are expected to be temporary.

The 2005 NDSt also outlines four guidelines that structure DoD's strategic planning and decision making:

- Active, layered defense,
- Continuous transformation,
- Capabilities-based approach, and
- Managing risks.[13]

[13] *National Defense Strategy of the United States of America* (2005, p. iv).

With regard to risks, the NDSt states that DoD will consider the full range of risks associated with resources and operations and manage clear trade-offs across the Department.

In addition, the *2006 QDR* outlines a number key differences in DoD strategy under the aegis of Transformation. A few of the differences relating to force structure might impact the NDS:

- From responding after a crisis starts (reactive) – to preventive actions so problems do not become crises (proactive) . . . .
- From static defense, garrison forces – to mobile, expeditionary operations . . . .
- From separate military Service concepts of operation – to joint and combined operations . . . .
- From exposed forces forward – to reaching back to CONUS to support expeditionary forces . . . .
- From broad-based industrial mobilization – to targeted commercial solutions . . . .
- From vertical structures and processes (stovepipes) – to more transparent, horizontal integration (matrix) . . . .
- From the U.S. military performing tasks – to a focus on building partner capabilities.[14]

With regard to the concept of a stockpile, the *2006 QDR*, on pages 89 and 90, cites the need to revise U.S. law and regulations to allow greater global sourcing of defense supplies:

> Recent legislative changes remove some of the impediments to helping partners engaged in their own defense, but greater flexibility is urgently needed. The Department will seek to:
>
> - Establish a Defense Coalition Support Account to fund and, as appropriate, *stockpile* routine defense articles such as helmets, body armor and night vision devices for use by coalition partners. [italics added]
> - Expand Department authority to provide logistics support, supplies and services to allies and coalition partners, without reimbursement as necessary, to enable coalition operations with U.S. forces.
> - Expand Department authority to lease or lend equipment to allies and coalition partners for use in military operations in which they are participating with U.S. forces.
> - Expand the authorities of the Departments of State and Defense to train and equip foreign security forces best suited to internal counterterrorism and counter-insurgency operations . . . .

[14]Office of the Secretary of Defense, *2006 Quadrennial Defense Review,* pp. vi-vii.

The *2006 QDR*, on page 38, also assumes both a steady-state and surge force capacity, but there is no discussion of the need for a stockpile or material reserve for these purposes:

Conduct and Win Conventional Campaigns

- Steady-state – deter inter-state coercion or aggression through forward deployed forces, enable partners through theater security cooperation, and conduct presence missions. These activities include day-to-day presence missions, military-to-military exchanges, combined exercises, security cooperation activities and normal increases in readiness during the seasonal exercises of potential adversaries.
- Surge – wage two nearly simultaneous conventional campaigns (or one conventional campaign if already engaged in a large-scale, long-duration irregular campaign), while selectively reinforcing deterrence against opportunistic acts of aggression. Be prepared in one of the two campaigns to remove a hostile regime, destroy its military capacity and set conditions for the transition to, or for the restoration of, civil society.

HOMELAND DEFENSE

As described in the White House's *National Strategy for Homeland Security* (2002), the strategic objectives of homeland security are, in order of priority, as follows:

- Prevent terrorist attacks within the United States;
- Reduce America's vulnerability to terrorism; and
- Minimize the damage and recover from attacks that do occur.

Recovery includes the full range of efforts to build and maintain various financial, legal, and social systems to recover from all forms of terrorism. The United States must be prepared to protect and restore institutions needed to sustain economic growth and confidence, rebuild destroyed property, assist victims and their families, heal psychological wounds, and demonstrate compassion, recognizing that we cannot automatically return to the preattack norm.

The *National Strategy for Homeland Security* aligns and focuses homeland security functions into six critical mission areas: intelligence and warning, border and transportation security, domestic counterterrorism, protecting critical infrastructure, defending against catastrophic terrorism, and emergency preparedness and response. The first three mission areas focus on preventing terrorist attacks; the next two on reducing our nation's vulnerabilities; and the final one on minimizing the damage and recovering from attacks that do occur.

The U.S. military has ongoing and emergency roles in each of these mission areas. DoD contributes to homeland security through its military missions overseas, homeland defense, and support to civil authorities. There are three circumstances under which DoD would be involved in improving security at home. In extraordinary circumstances, it would conduct military missions such as combat air patrols or maritime defense operations. Plans for such contingencies will continue to be coordinated, as appropriate, with the National Security Council, the Homeland Security Council, and other federal departments and agencies.

Second, DoD would be involved during emergencies such as responding to an attack or to forest fires, floods, tornadoes, or other catastrophes. In these circumstances, the Department may be asked to act quickly to provide capabilities that other agencies do not have. It would also take part in limited-scope missions where other agencies have the lead—for example, security at a special event like the Olympics. Third, in response planning, DoD has responsibility for the infrastructure protection plan, vulnerability assessment, and threat warning for the defense industrial base.

The importance of military support to civil authorities as the latter respond to threats or acts of terrorism is recognized in Presidential decision directives and legislation. Military support to civil authorities pursuant to a terrorist threat or attack may take the form of providing technical support and assistance to law enforcement; assisting in the restoration of law and order; loaning specialized equipment; and assisting in consequence management. The U.S. Northern Command is the military command that has direct responsibility for the following:

- Conducting operations to deter, prevent, and defeat threats and aggression aimed at the United States and its territories and interests within the assigned area of responsibility and
- Providing defense support for civil authorities, as directed by the President or Secretary of Defense, including consequence management operations. [15]

These specific homeland security missions may have an impact on the National Defense Stockpile in the following areas:

- Major military operations in the United States requiring a surge of logistics support, such as wide-area infrastructure protection or extensive disaster relief.
- Disruption (physical attack, natural disaster, pandemic illness) of vulnerable critical supply nodes, such as a mineral processing plant, a transportation center, or a consolidated supply depot that would impact military logistics.

[15]See Web site of the U.S. Northern Command at http://www.northcom.mil. Accessed December 2007.

C

Defining Twenty-first Century Defense Materials Needs

It is widely accepted that the military in the twenty-first century will need to communicate faster, more reliably, and on a global scale. New threats require new materials for the technology for their detection. New tasks will require new weapons and new materials to make possible new and better delivery platforms. The new systems of the twenty-first century military will also need to be multifunctional, self-diagnosing and self-healing, low cost, low maintenance, environmentally acceptable, and extremely reliable. A number of studies over the last several years consider how new threats, new adversaries, and emerging disruptive technologies have brought new challenges to which the nation and, specifically, the Department of Defense and the Department of Homeland Security must respond.

A Defense Science Board (DSB) report[1] suggested that the speed with which knowledge spreads and technology is applied is one of these challenges. In its report the DSB assessed defense and military needs and synthesized nine high-priority military areas:

- Biological warfare defense that is based on immediate detection and then defeat.
- Ability to find and correctly identify difficult targets, both static and mobile.

[1]DSB, *Defense Science and Technology* (2002). Available at http://www.acq.osd.mil/dsb/reports/sandt.pdf. Hereinafter referred to as *Defense S&T.*

- Support for high-risk operations by means such as unmanned systems capable of high-risk tactical operations.
- Missile defense that is cost effective and exhibits low leakage against tactical and strategic missiles and unmanned aerial vehicles.
- Affordable precision munitions that are resilient to countermeasures.
- Enhanced human performance that overcomes natural limitations on cognitive ability and endurance.
- Rapid deployment and employment of forces globally against responsive threats.
- Global effects that can be delivered rapidly, anywhere.

Although not released until 2002, the *Defense S&T* report was completed only months before the tragic events of September 11, 2001. While the central assessments of the report remain valid, there is no doubt that after those events there was a dramatic refocusing of the nation's attention to national security and, most importantly, to homeland security. September 11 caused many new assessments to be undertaken, one of which was a study by the National Research Council (NRC)[2] of the contributions science and technology might make to counterterrorism.

The aim of *Making the Nation Safer* was to help the federal government—and, more specifically, the Executive Office of the President—enlist the nation's and the world's scientific and technical community in a timely response to the threat of catastrophic terrorism. The terms of reference for the study called for (1) a careful delineation of a framework for the application of science and technology to countering terrorism, (2) the preparation of research agendas in nine key areas,[3] and (3) the examination of a series of crosscutting issues. Overall, the authoring committee aimed to identify scientific and technological means by which the nation might reduce its vulnerabilities to catastrophic terrorist acts and mitigate the consequences of such acts when they occur.

The eight panels of preeminent scientists, engineers, and physicians working on *Making the Nation Safer* identified 14 "most important" technical initiatives. Each was either an immediate application of an existing technology or an urgent research opportunity:

- Immediate applications of existing technologies
  —Develop and utilize robust systems for the protection, control, and

[2]NRC, *Making the Nation Safer: The Role of Science and Technology in Countering Terrorism* (Washington, D.C.: The National Academies Press, 2002). Hereinafter referred to as Making the Nation Safer.

[3]Biological sciences; chemical sciences; nuclear and radiological sciences; information technology and telecommunications; transportation; energy facilities; cities and fixed infrastructure; behavioral, social, and institutional issues; and systems analysis and systems engineering.

accounting of nuclear weapons and special nuclear materials at their sources.
- —Ensure production and distribution of known treatments and preventatives for pathogens.
- —Design, test, and install coherent, layered security systems for all transportation modes, particularly shipping containers and vehicles that contain large quantities of toxic or flammable materials.
- —Protect energy distribution services by improving security for supervisory control and data acquisition (SCADA) systems and providing physical protection for key elements of the electric-power grid.
- —Reduce the vulnerability and improve the effectiveness of air filtration in ventilation systems.
- —Deploy known technologies and standards for allowing emergency responders to reliably communicate with one another.
- —Ensure that trusted spokespersons will be able to inform the public promptly and with technical authority whenever the technical aspects of an emergency are dominant in the public's concerns.

• Urgent research opportunities
- —Develop effective treatments and preventatives for known pathogens and those that could emerge.
- —Develop, test, and implement an intelligent, adaptive electric-power grid.
- —Advance the practical utility of data fusion and data mining for intelligence analysis, and enhance the security of information against cyber attacks.
- —Develop new and better technologies that can be used in, for example, protective gear, sensors, and communications systems for emergency responders.
- —Advance engineering design technologies and fire-rating standards for blast- and fire-resistant buildings.
- —Develop sensor and surveillance systems for use against a wide range of targets; such systems would provide useful information for emergency officials and decision makers.
- —Develop new methods and standards for filtering air against chemicals and pathogens and for decontamination.

It is clear that materials will play a role in most if not all of the 9 high priorities identified in *Defense S&T* and the 14 initiatives identified in *Making the Nation Safer*. Understanding the risks to the supply of critical materials and learning how to mitigate them are, therefore, essential.

Another NRC report considered the narrower topic of how materials research could contribute to meeting twenty-first century military needs. The Department of Defense (DoD) asked the NRC to identify and prioritize the materials and processing R&D required, and the resulting study, released in 2003, explored the revolutionary defense capabilities and looked at five classes of materials: [4]

- Structural and multifunctional materials,
- Energy and power materials,
- Electronic and photonic materials,
- Functional organic and hybrid materials, and
- Bioderived and bioinspired materials.

In considering the opportunities for these materials, the study identified the following core tasks for the U.S. military:

- Projecting military power over long distances;
- Maintaining the capability to fight far from home;
- Coping with the eroding infrastructure of overseas bases;
- Safeguarding the homeland; and
- Adjusting to major changes in warfare, including joint-service operations, peacekeeping as part of a multinational coalition, and the growing number of humanitarian missions.

Defense After Next concluded that certain trends in warfare will continue:

- The need will increase for a precision strike force that can maneuver rapidly and effectively and survive an attack while far from the home base.
- The force must be able to conceal its activities from an enemy while detecting enemy activities.
- Advances in information technology will increase coordination among forces. Global awareness through real-time networked sensors and communications will facilitate command and control and enable precision strikes.
- Using unmanned vehicles, information will be gathered in new ways, military power will be delivered remotely, and the risk of casualties will be reduced.
- Fighting in urban areas will increase, demanding entirely different strategies and equipment.
- Guerilla warfare, too, will necessitate new strategies and weapons.

[4]NRC, *Materials Research to Meet Twenty-first Century Defense Needs,* Washington, D.C.: The National Academies Press (2003). Commonly called *Defense After Next* and hereinafter referred to by that name.

Defense After Next concluded that DoD needs various types of functionality, alone and in combination, for its military systems. Improvements in existing materials and breakthroughs in new materials and combinations of materials will be needed to develop new capabilities. Examples of the types of materials needed are as follows:

- Lightweight materials that provide functionality equivalent to that of heavier analogues.
- Materials that enhance protection and survivability;
- Stealth materials;
- Electronic and photonic materials for high-speed communication;
- Sensor and actuator materials;
- High-energy-density materials; and
- Materials that improve propulsion technology.

More details of this needs-based analysis can be found in the full report, including subpanel reports on the five classes of materials. The report concludes as follows:

> Future defense systems could employ advanced materials that are self-healing, can interact independently with the local environment, and can monitor the health of a structure or component during operation. Advanced materials could act as a host for evolving technologies, such as embedded sensors and integrated antennas. Advanced materials must also deliver traditional high performance in structures; protect against corrosion, fouling, erosion, and fire; control fractures; and serve as fuels, lubricants, and hydraulic fluids. The next 20 years will present the materials community with daunting challenges and opportunities. Requirements for material producibility, low cost, and ready availability will be much more demanding than they are today. On the other hand, spurred by the accelerated pace of advances in electronics and computation, the performance, life span, and maintainability of materials will be greatly enhanced. Some of the advances will result from R&D undertaken by commercial enterprises for competitive advantage in areas like telecommunications and computation. In other areas, however, DOD may have to bear the funding burden directly. In these special areas, considerable funding will be necessary not only to identify critical new materials, but also to accelerate their progress through development to applications in the defense systems of the future. (NRC, *Materials Research to Meet 21st Century Needs,* 2003, p. 7)

D

Rare Earth Elements

The lanthanide series of rare earth elements (REEs), whose atomic numbers range from 57 through 71, are listed in Box D-1. Scandium and yttrium are also often included in lists of REEs. All except promethium occur in nature. Lanthanum through samarium, as well as scandium and yttrium, are often termed the light rare earth elements (LREEs) and europium through lutetium are the heavy rare earth elements (HREEs).[1]

The term "rare earths" is a misnomer since REEs are fairly abundant in Earth's crust, although when they were originally discovered they were thought to be scarce. "Earth" is an obsolete term for oxide, since they were commonly found as oxides.

The rare earths are no longer mined in the United States. A rare earth fluocarbonate, bastnasite, used to be mined and processed near Mountain Pass, California, by Molycorp. However, concentrates, intermediate compounds, and some oxides were available in 2006, and the United States consumed them internally and even exported them. It is estimated that the rare earths consumed in this country every year have a value of more than $1 billion. In 2005, rare earths were estimated to be used as automotive catalytic converters (32 percent); metallurgical additives and alloys (21 percent); glass polishing and ceramics (14 percent); rare earth phosphors for lighting, televisions, computer monitors, radar, and x-ray intensifying film (10 percent); petroleum refining catalysts (8 percent); permanent

[1]For information on the REEs see http://minerals.usgs.gov/minerals/pubs/commodity/rare_earths/.

BOX D-1
Lanthanide Series of Rare Earth Elements

Lanthanum (La)	Cerium (Ce)	Praseodymium (Pr)
Neodymium (Nd)	Promethium (Pm)	Samarium (Sm)
Europium (Eu)	Gadolinium (Gd)	Terbium (Tb)
Dysprosium (Dy)	Holmium (Ho)	Erbium (Er)
Thulium (Tm)	Ytterbium (Yb)	Lutetium (Lu)

magnets (2 percent); and other uses (13 percent) (USGS, 2007). The little recycling that is done is mostly carried out on permanent magnet scrap. In the aggregate between 2002 and 2005 the countries that supplied REEs to the world market, along with the share of the demand they satisfied, are as follows: China (76 percent); France (9 percent); Japan (4 percent); Russia (3 percent); and other (8 percent). In 2006 imports to and exports from the United States increased over 2005, and this trend may be expected to continue in the future.

Rare earth compounds are used in automotive catalytic converters and other applications. For instance, cerium compounds are used mainly for automotive catalytic converters, glass polishing, and glass additives. Yttrium compounds are used in fiber optics, lasers, oxygen sensors, phosphors for fluorescent lighting, color televisions, electronic thermometers, x-ray intensifying screens, pigments, superconductors, and other items. Mixed rare earth compounds and rare earth metals and their alloys are used in permanent magnets, base-metal alloys, superalloys, pyrophoric alloys, lighter flints, and armaments; the amounts used have increased lately. The use of rare earth chlorides for fluid cracking catalysts in oil refining has declined.

Molycorp has shut down mining at the Mountain Pass location because of wastewater disposal problems but was expected, at the time of writing, to restart processing stockpiled ore late in 2007. Mining may not start for a couple of years (Thorne, 2007, personal communication).

REEs do not need to be as concentrated as most minerals for economic mining. The best source minerals for them are bastnasite and monazite. The largest deposits of bastnasite are those at Baiyun Obo (Inner Mongolia, China) and Mountain Pass, California, with the later already having been mentioned. Monazite deposits occur in Australia, Brazil, China, India, Malaysia, South Africa, Sri Lanka, Thailand, and the United States. Other minerals containing rare earths include apatite, cheralite, eudialyte, secondary monazite, loparite, phosphorites, rare-earth-bearing (ion adsorption) clays, spent uranium solutions, and xenotime. It has been speculated

BOX D-2
Actinide Series of Rare Earth Elements

Actinium (Ac)	Thorium (Th)	Protactinium (Pa)
Uranium (U)	Neptunium (Np)	Plutonium (Pu)
Americium (Am)	Curium (Cm)	Berkelium (Bk)
Californium (Cf)	Einsteinium (Es)	Fermium (Fm)
Mendelevium (Md)	Nobelium (No)	Lawrencium (Lr)

that undiscovered deposits are large compared to expected demand. Exploration for rare earths is continuing in Canada near Yellowknife and in Quebec around Strange Lake (Hedrick, 2007).

Sometimes the elements with atomic numbers 89 through 103 are also considered to be REEs. Listed in Box D-2, they are referred to as actinides. Actinium, thorium, protactinium, and uranium are the only elements of the actinide series that occur in nature. The rest are manmade and obtained by bombarding the naturally occurring actinides with neutrons or heavy particles in cyclotrons; they are known as transuranium elements.

Actinium is found along with uranium, a product of the latter's decay. It is used in research as a tracer element and as a thermoelectric power source in satellites.

Protactinium is scarce and used only for research. It is highly radioactive and toxic. It occurs in very small amounts in pitchblende and in some ores in the Democratic Republic of the Congo.

Thorium occurs naturally, primarily in monazite but also in other minerals; it is used as a fuel in some nuclear reactors. It is also used to alloy magnesium and coat tungsten and in tungsten-arc welding, heat-resistant ceramics, and sometimes as a shield against radiation. Thorium oxide is used in gas lamp mantles, high-temperature crucibles, lenses, and as a catalyst for oil refining and other chemical reactions. The largest known reserves of thorium are in Australia, India, the United States, Norway, Canada, South Africa, and Brazil.

Uranium occurs naturally, primarily as U^{238} (over 99 percent) but also as U^{235} and in very small amounts as U^{234}. Since the half-life of U^{238} is 4.47 billion years, it is useful for dating materials. The minerals in which it occurs include uraninite (the most common), autunite, uranophane, tobernite, and coffinite. It is also found in some monazite sands. Uranium also occurs in seawater, and in the 1980s the Japanese proved that it could be extracted from the water (JAERI, 1999).

Uranium is fissile; upon bombardment with slow neutrons its isotope U^{235} becomes the very short-lived U^{236}, which instantaneously divides into two smaller nuclei, releasing its binding energy along with more neutrons. If these neutrons are absorbed by other U^{235} nuclei, then a chain reaction occurs. If the excess neutrons are not absorbed, slowing down the reaction, an explosion results. The first nuclear bomb was based on this principle of nuclear fission.

Depleted uranium alloyed with small amounts of other elements is used for high-density penetrators. This use has been criticized because of the residual uranium left in the soil. It serves as counterweights for aircraft control surfaces, as ballast for missile reentry vehicles, and in inertial guidance devices. It is also the fuel source for nuclear submarines.

The main civilian use of uranium is in nuclear reactors for power generation. Before its radiation characteristics were understood, uranium was used in yellow glass, pottery dyes, and photographic film.

Canada, Australia, and Kazakhstan are the largest producers of uranium, with the largest reserves being in Australia and Canada. In the United States it occurs in the Colorado Plateau, which spans Colorado, Utah, New Mexico, and Arizona.

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E

Other U.S. Stockpiles

Below are descriptions of some other U.S. stockpiles—of both materials and other "usables"—with the idea that these other models might provide insights into how government can assure the supply of an item, a commodity, or a material.

STRATEGIC NATIONAL STOCKPILE PROGRAM AT THE DEPARTMENT OF HEALTH AND HUMAN SERVICES

First established in 1999 as the National Pharmaceutical Stockpile Program, the Strategic National Stockpile (SNS) program[1] has large quantities of medicine and medical supplies to protect the U.S. public in the event of a public health emergency—for example, a terrorist attack, a flu outbreak, or an earthquake. The SNS is designed to deliver medicines within 12 hours to any state in the United States once federal and local authorities agree that local supplies have run out and the SNS is needed. Each state has plans to receive and distribute SNS medicine and

[1]In 1999 Congress charged the Department of Health and Human Services (HHS) and the Centers for Disease Control and Prevention (CDC) with the establishment of the National Pharmaceutical Stockpile (NPS). The mission was to provide a resupply of large quantities of essential medical materiel to states and communities during an emergency within 12 hours of the federal decision to deploy. The Homeland Security Act of 2002 tasked the Department of Homeland Security (DHS) with defining the goals and performance requirements of the SNS program as well as managing the deployment of assets. Effective March 1, 2003, the NPS became the Strategic National Stockpile (SNS) program, managed jointly by DHS and HHS. In 2004, with the signing of the BioShield legislation, the SNS Program was returned to HHS for oversight and guidance.

medical supplies to local communities as quickly as possible. SNS medicines are delivered free. The SNS is designed to have enough medicines stockpiled to protect people in several large cities at the same time. The SNS program is operated by the Centers for Disease Control and Prevention (CDC) at the Department of Health and Human Services.

The SNS holds supplies of antibiotics, chemical antidotes, antitoxins, life-support medications, intravenous administration devices, airway maintenance supplies, and medical/surgical items. The first line of support available from the SNS program is a supply of 12-hour Push Packages, each weighing up to 50 tons and comprising 130 containers (see Figure E-1). These are caches of pharmaceuticals, antidotes, and medical supplies designed to provide rapid delivery of a broad spectrum of supplies in the early hours of an event. These packages are strategically located in secure warehouses for quick deployment to a designated site within 12 hours. They are constructed so that they can be loaded onto trucks or cargo aircraft without being repackaged. If the incident requires additional pharmaceuticals and/or medical supplies, follow-on vendor-managed-inventory (VMI) supplies will be shipped to arrive within 24 to 36 hours. VMI supplies are stored by major pharmaceutical vendors until shipment.

FIGURE E-1 A single Push Package weighs 94,424 pounds and fills either one wide-body aircraft or seven tractor trailers. The Strategic National Stockpile program pledges to deliver the prepackaged supplies within 12 hours of the federal (DHS) decision to deploy. SOURCE: Centers for Disease Control and Prevention, Atlanta, Georgia. Available at http://www.bt.cdc.gov/stockpile/.

To receive SNS assets, the governor of an affected state or an appointed designee, such as a state health official, can request the deployment of the SNS from the director of the CDC. Once the request has been made, the director has the authority, in consultation with the Surgeon General and the Secretary of Health and Human Services, to order the deployment of the SNS. The decision to deploy SNS assets may be based on evidence of an overt release of a biological or chemical agent or some other emergency that might adversely affect the public's health.

The SNS has been used twice. On September 11, 2001, Governor of New York, George E. Pataki, requested assistance of the SNS program. In response, the CDC delivered a 50-ton package of supplies to New York City within 7 hours of the federal deployment order and had a team on the ground to meet it. In October 2001, the SNS program delivered assistance by means of VMI packages to the health department in Palm Beach County, Florida, after a case of *Bacillus anthracis* (anthrax) had been diagnosed. The assistance included 100 doses of antibiotics, delivered by air.

Medical materiel stock in the SNS program is rotated and kept within potency shelf-life limits by means of quarterly quality assurance and quality control checks, annual 100 percent inventory of 12-hour Push Package items, and inspections of environmental conditions, security, and overall package maintenance.

STRATEGIC PETROLEUM RESERVE

The Strategic Petroleum Reserve (SPR) is the world's largest supply of emergency crude oil. The federally owned oil stocks are stored in huge underground salt caverns along the coastline of the Gulf of Mexico. Although the idea of a petroleum reserve had been around for some time,[2] it was not established until 1975, following the 1973-1974 oil embargo. President Ford set the SPR into motion when he signed the Energy Policy and Conservation Act (EPCA) on December 22, 1975. The Act authorized the stockpiling of up to 1 billion barrels of petroleum. Today, the SPR can hold 727 million barrels.[3] The facilities and crude oil represent an investment of about $22 billion in energy security ($5 billion for facilities and $17 billion for crude oil).[4] The Energy Policy Act of 2005 directs the Secretary of Energy to fill the SPR to its authorized 1 billion barrel capacity, and this is now being done.

[2]Secretary of the Interior Ickes advocated the stockpiling of emergency crude oil in 1944, and President Truman's Minerals Policy Commission proposed a strategic oil supply in 1952. President Eisenhower suggested an oil reserve after the 1956 Suez Crisis. The Cabinet Task Force on Oil Import Control recommended a similar reserve in 1970.

[3]For information on the current SPR inventory, see http://www.spr.doe.gov/dir/dir.html. Accessed May 2007.

[4]For further information, see http://www.fossil.energy.gov/programs/reserves/spr/index.html. Accessed May 2007.

Decisions to withdraw crude oil from the SPR are made by the President under the authority of EPCA. In the event of an energy emergency, SPR oil would be distributed by competitive sale. It takes 13 days from the Presidential decision for the oil to enter the commercial market. The President can order a full drawdown of the reserve to counter a "severe energy supply interruption" or a limited drawdown. In addition, the Secretary of Energy is authorized to carry out test drawdowns and distribution of crude oil from the SPR.

The SPR has been used under emergency circumstances only twice, during Operation Desert Storm[5] in 1991 and after Hurricane Katrina[6] in 2005. DOE has the authority to exchange oil from the reserve, and such exchanges have been used to replace less suitable grades of crude oil with higher-quality crudes and for limited, short-duration actions to assist petroleum companies in resolving oil delivery problems. In 2000, crude oil from the reserve was exchanged for storage capacity and stocks to create the Northeast Heating Oil Reserve. During the fall of 2005, an exchange was conducted at the request of refineries in the Gulf region when Hurricane Katrina disrupted scheduled deliveries. During 2006, small exchanges occurred in January and June, when accidents in shipping channels disrupted marine deliveries to refiners.

Since early 1999, the SPR has been filled by means of the joint DOE/Department of the Interior program Royalty-in-Kind. This program applies to oil owed to the U.S. government by producers who operate leases on the federally owned Outer Continental Shelf. These producers provide between 12.5 percent and 16.7 percent of the oil they produce to the U.S. government, which acquires either the oil itself or the equivalent dollar value.

STRATEGIC HELIUM RESERVE

Today, the federal helium reserve comprises over 1 billion cubic feet of helium gas stored at the Cliffside facility, about 12 miles northwest of Amarillo, Texas. The reserve goes back to World War I, when the task of establishing a domestic source of helium was given to the U.S. Bureau of Mines (BOM). Helium production in the United States evolved over the years that followed as natural gas fields that were good sources of helium came on line and then closed down. In 1960, Congress enacted the Helium Act Amendments (P.L. 86-777), which directed the Secretary of the Interior to (1) acquire and conserve helium and (2) buy commercial crude helium using funds borrowed from the Treasury. The law permitted private helium

[5]For further information, see http://www.fossil.energy.gov/programs/reserves/spr/spr-drawdown.html#desertstorm. Accessed May 2007.

[6]For further information, see http://www.fossil.energy.gov/programs/reserves/spr/spr-drawdown.html#katrina_sale. Accessed May 2007.

production—the BOM subsequently arranged for five private plants to recover helium from natural gas so that BOM would become a buyer of last resort. The reserve served as a supply of helium for the government, which, like private owners, sold it to users. In this regard the reserve was not a stockpile in the sense of the petroleum reserve or the government-sanctioned stockpile of medicines.

By 1995, the reserve had collected 1 billion cubic meters of helium along with $1.4 billion in debt. In response, and given that more than 90 percent of domestic demand at the time was being satisfied from private sources, Congress acted to phase out the reserve. The Helium Privatization Act of 1996 (P.L. 104–273) directed the Department of the Interior (DOI) to commence the sale of 850 million scm of the federal helium reserve by January 1, 2005, completing the sale by January 1, 2015. The legislation also directed DOI to enter into appropriate arrangements with the NRC to study and report on whether such disposal of helium reserves would have a substantial adverse effect on U.S. scientific, technical, biomedical, or national security interests. In 2000, an NRC report[7] found that given the trends in the helium supply market at that time, the proposed liquidation of the federal reserve would not have a substantial impact in the next two decades. But the committee also recommended that a follow-up study be undertaken to ensure that the legislation would have no adverse long-term (beyond 2020) effects and that sufficient helium would continue to be available after 2020. The NRC report also recommended research into both enhanced helium conservation and exploration technologies. Unless helium is extracted from natural gas, it is lost to the atmosphere when the gas is burned. Helium in the atmosphere is eventually lost to space and is therefore unrecoverable.

Sales from the helium reserve commenced in 2003 and at the time this report was being written, about one third of the helium had been sold in five sales on the open market. A sixth sale was planned for the fall of 2007, but this time against the backdrop of a helium shortage.[8] The price for which the reserve is selling its stock is based on a formula in the authorizing legislation designed to pay off the reserve's debt. The amount of helium that can be sold in each sale is limited by the capacity of the reserve's delivery system. No releases other than the sales have been made in recent years.

[7]NRC, 2000, *The Impact of Selling the Federal Helium Reserve* (Washington, D.C.: The National Academies Press). Available at http://books.nap.edu/openbook.php?isbn=0309070384. Accessed May 2007.

[8]See http://www.theledger.com/apps/pbcs.dll/article?AID=/20070507/NEWS/705070369/1039. Accessed June 2007.

THE CIVILIAN RESERVE AIR FLEET: A STOCKPILE MODEL?

One example of a U.S. government program that seeks to maintain surge capacity for military crises in ways broadly analogous to materials stockpiling is the Civilian Reserve Air Fleet (CRAF). The CRAF involves commitments by U.S. airlines (both passenger and cargo carriers) to provide airlift capacity (cargo, passenger, and medevac services) to the U.S. military on relatively short notice (24-48 hours). Airline companies are required to convert their aircraft to meet specific military requirements within this period of time. Although the carriers continue to operate the aircraft, the Air Force Air Mobility Command (AMC) controls the aircraft during mobilization of the CRAF. The CRAF is organized into three broad segments: international, domestic, and aeromedical services.

Airlines participating in the CRAF do not receive any direct payments for maintaining aircraft that can be converted on short notice to meet military requirements. Instead, their participation is rewarded by eligibility for peacetime military air transportation contracts. For FY2005, CRAF carriers were guaranteed contracts worth $418 million by the Air Force, and the Air Force AMC estimated that an additional $1.5 billion in contracts for transportation services would be awarded to participating airlines, although these commitments were not guaranteed.

CRAF has been activated only twice in its 54-year history: in the 1991 Desert Storm action (August 1990-May 1991) and during the U.S. military action in Iraq (February-June 2003). As of April 2005, 40 carriers and 1,126 aircraft were enrolled in CRAF, more than 1,000 of them in the international segment of the program.

CRAF provides surge capacity for the military services at a much lower cost than they could provide it for themselves. Nevertheless, the financial instability that afflicts the U.S. airline industry and the growing military interest in transport aircraft that can operate in more primitive landing facilities (shorter runways, poor instrumentation, etc.) are leading the military to consider alternatives to CRAF for what is likely to be the larger surge capacity required for military airlift operations. For their part, carriers have complained about the occasional failure of the military services to use their aircraft once the equipment has been activated and converted to military specifications, because they are directly compensated only when their aircraft are used for airlift. They have also complained that the military services do not pay enough to fully compensate them for use of their equipment.

F

Case Study: Beryllium

The United States is one of only three countries known to process beryl ores and beryllium concentrates into beryllium products. Brush Resources, Inc., a subsidiary of Brush Engineered Materials (BEM), extracts bertrandite from open pit mines near Delta, Utah, and converts the bertrandite, along with imported beryl and beryl from the NDS, into beryllium hydroxide.

At year-end 2005, BEM reported proven bertrandite reserves in Utah of about 5.99 million dry metric tons. This represented about 16,000 tons of contained beryllium, which would be sufficient for more than 100 years of operation based on average production levels in recent years.[1] Thus, there is no shortage of raw material. The problem is production capacity.

Beryllium is highly toxic and there have been several health and environmental problems reported. Correction of those problems is driving up the cost of producing beryllium and stimulating interest in the development of substitute materials. Table F-1 shows the uses of beryllium. Consumption by use is shown in Figure F-1. Since 1999, consumption has been declining. Electronics has been the largest user.

In 1994, after completing its assessment of the stockpile requirements, the Institute for Defense Analysis concluded there was no need to stockpile beryllium, and in 1995 DoD recommended to Congress that the beryllium goals be dropped to zero. On March 25, 1996, DoD released an assessment of the global advanced

[1]USGS *Minerals Yearbook*, 2005.

TABLE F-1 Uses of Beryllium

National Defense	Commercial
Airborne forward-looking infrared systems	Battery contacts and electronic connectors in cell phones and base stations
Guidance systems on existing strategic missiles	Aerospace castings
Surveillance, communications, and other satellites	High-definition and cable television
Missile defense systems	Underwater fiber-optic cable systems
Aircraft brakes	High-density circuits for high-speed computers and automotive ignition systems
Nuclear reactor rods and warheads	Pacemakers and other medical devices

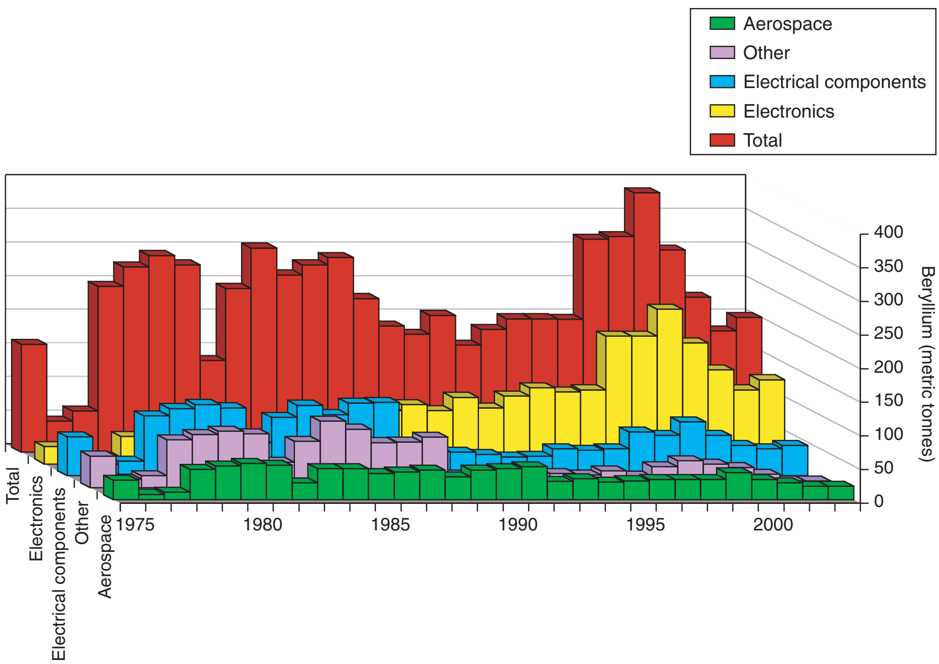

FIGURE F-1 Annual consumption of beryllium by end use. SOURCE: *USGS Minerals Yearbook* (2005).

materials technology and industrial base.[2] According to the press release that accompanied that report's release,

> This assessment found that there are no issues of assured, affordable access to the specialty metals of superalloys, titanium and beryllium, and that industry downsizing to reduce overcapacity will not be inconsistent with future defense requirements.

[2]DoD, Memorandum for Correspondents (Memorandum No. 045-M, March 25, 1996). Available at http://www.defenselink.mil/news/Mar1996/m032596_m045-96.html. Accessed June 2007.

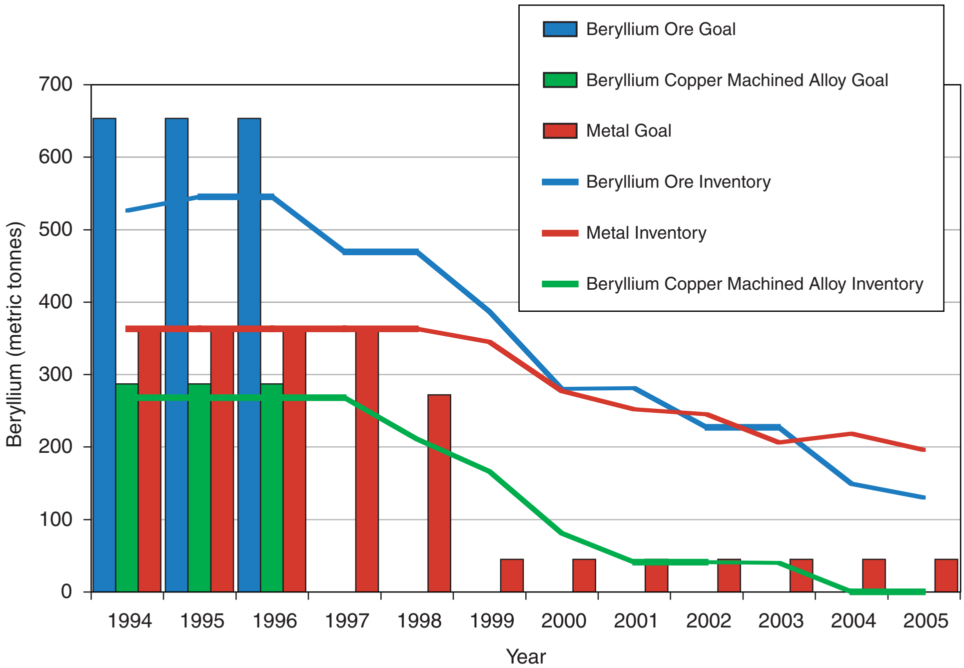

FIGURE F-2 The trend in inventories and goals by type of beryllium. SOURCE: Data from *USGS, Minerals Yearbook,* various years.

Congress subsequently authorized disposal of all beryl ore and BCMA and a portion of the beryllium metal inventory (Figure F-2).

In 2000, BWI mothballed its beryllium metal production facility in Elmore, Ohio, citing obsolescence, economic, health, and safety reasons. The availability of excess inventory from the NDS may also have been a factor. It is not clear what, if any, reaction the DoD had to the closure, since no action was reported publicly by the government until 2003.

The issue of a domestic production source for beryllium was raised in the May 16, 2003, report of the House Armed Services Committee that accompanied its version of the FY2004 National Defense Authorization Act:[3]

> The committee is aware that the domestic supply of the strategic and critical metal beryllium is in danger of being depleted. Metallic beryllium is used extensively in DOD weapons systems, DOE strategic nuclear applications and several critical civilian applications. Moreover, the only domestic producer of metal beryllium has closed its primary metal production plant because of obsolescence. Therefore, the committee directs that the

[3]Available at http://www.dod.mil/dodgc/olc/docs/2004NDAA.pdf. Accessed September 2007.

> DOD conduct an in-depth study of the beryllium supply issue and make recommendations regarding how future access to beryllium could be assured.

Section 824 of the FY2004 National Defense Authorization Act directed the Secretary of Defense to submit a report by March 31, 2005, providing information on the following:

- The long-term supply of beryllium,
- The need for modernization of the primary sources of production of beryllium,
- Concepts for meeting the future defense requirements for beryllium, and
- Plans for maintaining a stable domestic industrial base for sources of beryllium through cooperative public-private partnerships, administration of the NDS, and other means.

A summary of the findings of the subsequent DoD study was included in the *Annual Industrial Capabilities Report to Congress*, issued in February 2005 (hereinafter called the *2005 Capabilities Report)*.[4] The report noted that the United States had lost its only capacity to manufacture primary beryllium metal in 2000, when the only producer, BWI, mothballed its production facility. Since then, BWI had relied on a dwindling supply of beryllium ingot from the NDS, which it purchased to meet defense and other needs for high-purity beryllium metal products.

The report estimated that the depletion date for NDS beryllium ingot inventories, based on annual growth in demand of 6 percent over at least the next 5 years, would be 2008. That could be extended until 2011 if anticipated imports of beryllium from Kazakhstan are sufficiently pure for lower purity applications. The *2005 Capabilities Report* noted that it would take 3-5 years to design, permit, construct, equip, and test a new primary beryllium facility no matter whether the manufacturing technology employed is the current one or a newer one.

Once the ingot is exhausted, beryllium in the form of hot pressed powder billet being held in reserve at the NDS could extend the depletion date for a few years if it is made available to the private sector. However, the report said that these reserves of beryllium should be released only as a last resort, serving as a hedge against delays in bringing the new facility on line.

The report concluded that even if the beryllium from Kazakhstan turned out to be pure enough for high-purity applications, the risks were too great:

[4]Available at http://www.acq.osd.mil/ip/docs/annual_ind_cap_rpt_to_congress-2005.pdf. Accessed September 2007.

- Dependence on Kazakhstan for production and Russia for feedstock and
- Transfer of BWI manufacturing technology to Kazakhstan could lead to the sale of high-purity beryllium metal to third-party countries, which might use it to make nuclear weapons or defense-related products.

The *2005 Capabilities Report* concluded that while imports are not a viable long-term option, private commercial investment is highly unlikely to be adequate. It suggested that the DoD begin a multiyear cost-share program with private industry, possibly through the Defense Production Act, to support the design, construction, and equipping of a new beryllium metal production facility, with the DoD share at $30 million to $45 million.

In response to the DoD report, the defense appropriations bill for 2005 directed that $3 million appropriated in the Defense Production Act be used for preliminary plant design, for a review of the permitting process, and for developing a 5-year plan to build the new plant. In the FY2006 President's Budget Request, DoD requested $6 million for the project, and Congress appropriated $7.8 million.

On November 30, 2005, BWI of Cleveland, Ohio, was awarded a contract to develop technology, and it agreed to share the cost of reestablishing and maintaining a domestic production capacity for primary, high-purity beryllium metal.

The DoD requested $7.5 million in 2007, and that was appropriated. Its budget submission for 2008 indicated that it planned to budget an additional $22.5 million for the project ($7.5 million in each year from 2008 through 2010). Thus, $40.8 million of federal funds is projected to be spent for the new facility.

DoD has been sponsoring research to develop substitute materials for beryllium. Two examples follow:

- In 2002, the Missile Defense Agency solicited proposals for substitutes.[5] The objective was to investigate and define a suitable beryllium substitute or beryllium alloy substitute that is affordable, possesses the appropriate profile and characteristics of beryllium or beryllium alloy, is producible in a production environment, and does not pose any of the health hazards associated with beryllium or beryllium alloy.
- In 2006, the Army solicited proposals for a similar project.[6] Its objective was the development of safe (nontoxic), reliable, cost-effective, and efficient composites that could replace beryllium components. The solicitation noted that previous work sponsored by the Navy (1980-1995) had demonstrated the possibility of developing composite materials with properties similar to those of beryllium for structural components.

[5]Project MDA 03-048: Define/Demonstrate Beryllium (Be) Substitute Material.

[6]A06-029: Hybrid Composite for Beryllium Replacement in Missile Defense Interceptors.

Whether significant progress on substitutes has been made is unclear at this time.

The requirement for stockpiling beryllium hot-pressed powder is driven not by the need to replenish after a conflict but by the need to assure a continuous supply to meet DoD and DOE programmatic needs attributable to the recent shutdown of the sole domestic processor of beryllium ore concentrates. As foreign suppliers are not considered reliable and the limited domestic supplies are being depleted it has been recommended that the current inventory be retained until the supply uncertainties are resolved.

This example shows that in some cases, use of Defense Production Act authorities to guarantee a U.S. source for a critical material may be preferable to maintaining a stockpile of such material.

G

Committee Membership

Robert H. Latiff, *Chair*, is vice president, chief engineer, and technology officer in SAIC's Space and Geospatial Intelligence Business Unit. He recently retired from the U.S. Air Force as a major general, with his last assignments at the National Reconnaissance Office as the director for systems engineering and as the director of advanced systems and technology. General Latiff was a career acquisition officer, managing large, complex systems such as the Cheyenne Mountain Complex, the Air Force's airspace management and landing systems, and the Joint Strategic Target Attack Radar System (JSTARS). Dr. Latiff holds a Ph.D. in materials science and a B.S. in physics from the University of Notre Dame.

Herman M. Reininga, *Vice-Chair,* retired as senior vice president of operations for Rockwell Collins. Mr. Reininga was responsible for overall management of Rockwell Collins's global production and material operations, including manufacturing, material, quality, and facilities activities. He has served on the Defense Science Board (DSB) and testified in front of the Senate Armed Services Committee on defense technology, acquisition, and the industrial base. He chaired the DSB's Production Technology Subgroup for Weapons Development and Production Technology Summer Studies Program that developed a manufacturing technology strategy for DoD. He is also called upon regularly to provide perspective for future manufacturing strategies. In June 2001, Mr. Reininga was inducted into the University of Iowa College of Engineering Distinguished Engineering Alumni Academy. In 1999, he received the prestigious Meritorious Public Service Citation from the Chief of Naval Research, Department of the Navy. In 1998 he was awarded the Defense Manufacturing Excellence award, endorsed by nine national trade associations and professional societies. Mr. Reininga is the current chair of the National Research Council's Board on Manufacturing and Engineering Design. He holds a B.S. in industrial engineering from the University of Iowa and a master's in industrial engineering from Iowa State University.

Carol L. Jones Adkins has a B.S. in chemical engineering from the University of New Mexico. She attended the California Institute of Technology and earned a Ph.D. in chemical engineering. At Sandia National Laboratories (SNL), Dr. Adkins has performed research in chemical vapor deposition of ceramics and tungsten, aerosol processing, cleaning with supercritical CO_2, and semiconductor wafer contamination and cleaning. She was program leader for the wafer cleaning project under the SEMATECH CRADA. In particular, Dr. Adkins led a team of researchers investigating the extension of standard wet cleaning techniques to the next generation of particle removal. She and her colleagues at Los Alamos National Laboratories were awarded the DOE Office of Industrial Technologies Commercialization Award for Supercritical CO_2 in 1995. She has led SNL personnel performing research and process development in encapsulation, adhesion, and fracture mechanics of organics. During this time, Dr. Adkins was involved in negotiating several new CRADAs between SNL and Goodyear in manufacturing and engineered products. Between 1996 and 2004, she was a manager, the deputy director, and the director of the Manufacturing Science and Technology Center at SNL. The center is responsible for developing advanced manufacturing science and technology at the SNL, along with building the prototypes for various programs. She was a member of the NRC's Board on Manufacturing and Engineering Design. Dr. Adkins's current assignments are as deputy to SNL's vice president of science and technology and partnerships and deputy to the director of the Nuclear Weapons Science and Technology program.

Bruce E. Blue is the CEO of Freedom Metals, Inc., a company that specializes in processing all grades of ferrous and nonferrous scrap materials. He is a graduate of the University of Oklahoma, where he earned his bachelor's in business administration. Previous to his employment with Freedom Metals, Mr. Blue was vice president of the nonferrous division of Louisville Scrap Metal Company, Inc. He is a member of the DoD Advisory Committee on the U.S. National Stockpile and of the Deposit Legislative Taskforce for the Commonwealth of Kentucky. Mr. Blue is on the board of directors for the Institute of Scrap Recycling Industries (IRIS) and is chairperson of the national IRIS convention and a speaker for many IRIS educational programs. Additionally, he serves as president of the Kentucky Scrap Processors and Recyclers.

Kenneth S. Flamm is the Dean Rusk Chair in International Affairs at the Lyndon B. Johnson School of Public Affairs at the University of Texas in Austin. He received a Ph.D. from the Massachusetts Institute of Technology in economics. From 1993 to 1995, Dr. Flamm served as principal deputy assistant secretary of defense for economic security and special assistant to the deputy secretary of defense for dual use technology policy. He was awarded DoD's Distinguished Public Service Medal in 1995 by Secretary Perry. Prior to his service at DoD, he spent 11 years as a senior fellow in the foreign policy studies program at the Brookings Institution. Dr. Flamm has been a professor of economics at the Instituto Tecnológico A. de México in Mexico City, the University of Massachusetts, and George Washington University. He has also been an adviser to the director general of income policy in the Mexican Ministry of Finance and a consultant to the Organisation for Economic Cooperation and Development, the World Bank, the Latin American economic system, DoD, the Department of Justice, the U.S. Agency for International Development, and the Office of Technology Assessment of the U.S. Congress. Dr. Flamm's publications include *Mismanaged Trade: Strategic Policy and the Semiconductor Industry* (1996), *Changing the Rules: Technological Change, International Competition, and Regulation in Communications* (editor, with Robert Crandell, 1989), *Creating the Computer: Government, Industry, and High Technology* (1988), and *Targeting the Computer: Governmental Support and International Competition* (1987). He is currently working on an analytical study of the post-Cold War defense industrial base. Dr. Flamm has been a member of the NRC's Board on Science, Technology and Economic Policy, and has served on a number of NRC committees on innovation and competitiveness.

Katharine G. Frase is vice president, technical and business strategy, IBM Software Group. Her team is responsible for technical strategy, business strategy, business development, standards, competitive analysis, and the application of advanced technologies across SWG. Dr. Frase received an A.B. in chemistry from Bryn Mawr College and a Ph.D. in materials science and engineering from the University of Pennsylvania. Before her current position at IBM, Dr. Frase was vice president of technology at IBM, in which role she was responsible for technical resources, recognition, assessment, and strategy across IBM. In 2006, in recognition of her distinguished contributions to engineering, she was elected as a member of the National Academy of Engineering (NAE). Earlier IBM responsibilities included management of process development, design/modeling methodology and production for chip carrier assembly, and final testing for IBM silicon products. Her research interests include mechanical properties/structural interactions in composites, high-temperature superconductors, solid electrolytes (fast ionic conductors), ceramic powder synthetic methods, and ceramic packaging. She chaired an IBM/Academy workshop on lead solder reduction actions, and in 1998 served as the packaging assurance manager for IBM worldwide. Dr. Frase has served as a member of the NRC's Board on Assessment of National Institute of Standards and Technology Programs and is currently the chair of the Panel on Materials Science and Engineering. Dr. Frase is the chair of the National Materials Advisory Board.

Donald E. Gessaman is a consultant to the EOP Group, a Washington, D.C., consulting firm specializing in environmental, energy, and other government-related issues, and to the EOP Foundation, a policy research and training activity. He has been the principal author of 11 editions of *Understanding the Budget of the United States Government*, a book addressing all aspects of the federal budget process, published annually by the EOP Foundation. In addition, Mr. Gessaman is a frequent lecturer on federal budget policy and processes at the Management Development Centers of the U.S. Office of Personnel Management and at federal agency training programs. In 1995, when Mr. Gessaman retired from the federal government, he was the deputy associate director for national security at the Office of Management and Budget (OMB) in the Executive Office of the President. During his 28 years at the OMB, he also served as a budget examiner, the Navy branch chief, and deputy chief of the National Security Division, which provides analyses and options on defense and intelligence resource issues, including the national defense materials stockpile, for the OMB director and the President. During his federal career, Mr. Gessaman received the OMB Professional Achievement award, the Presidential rank awards of Meritorious Executive and Distinguished Executive, and the Distinguished Public Service Medal from the Secretary of Defense. Mr. Gessaman's education includes an undergraduate degree in industrial management from the University of Cincinnati and a master's degree in industrial engineering from Stanford University. In addition, Mr. Gessaman completed the Program for Senior Executives in National and International Security at the Kennedy School of Government at Harvard University.

Stephen T. Gonczy is the founder of Gateway Materials Technology, Inc. (GMT), a scientific research and materials engineering consulting firm with a special focus on advanced ceramics and ceramic composites. Dr. Gonczy received his B.S. in mechanical engineering from Marquette University and his Ph.D in materials science and engineering from Northwestern University. He has over 25 years of industrial research and development experience in advanced materials for aerospace, automotive, and industrial power applications. Dr. Gonczy has been the principal investigator in many projects, including standardized tests for ceramic coatings and porous ceramics; processing and application of polymer-derived ceramics; import-export regulations for ceramic composites; materials database development for ceramic composites and cast metals; low-cost coatings for ceramic fibers; processing, properties, and stability of ceramic composites; and material design studies for Web publication. Dr. Gonczy currently holds leadership positions on two national ceramic technology committees. He is the chairman of ASTM C28 Advanced Ceramics and has over 20 years of technical author effort and leadership responsibilities for the committee. He is also the current chairman of the ceramic matrix composites working group for ASTM's *Composites Materials Handbook 17* (CMH-17) and has been an active member since 1996. Prior to founding GMT, Dr. Gonczy worked as a research scientist and a research group leader in advanced ceramics at Honeywell (then Allied Signal) Research Center. Dr. Gonczy was a member of the U.S. Army Reserve, serving in logistics and acquisition positions for over 25 years and retiring as a brigadier general in 2004.

Ralph L. Keeney is a research professor at the Fuqua School of Business at Duke University. He has a B.S. in engineering from the University of California at Los Angeles, an M.S. in electrical engineering from MIT, and a Ph.D. in operations research from MIT. Prior to joining the Duke faculty, Dr. Keeney was a faculty member in management and in engineering at MIT and at the University of Southern California, a research scholar at the International Institute for Applied Systems Analysis in Laxenburg, Austria, and the founder of the decision and risk analysis group of a large geotechnical and environmental consulting firm. Dr. Keeney is the author of many books and articles, including (with Howard Raiffa) *Decisions with Multiple Objectives* (reprinted by Cambridge University Press, 1993), which won the ORSA Lanchester Prize, and *Value-Focused Thinking: A Path to Creative Decision-making* (Harvard University Press, 1992), which received the Decision Analysis Society's Best Publication award. His latest book, *Smart Choices: A Practical Guide to Making Better Decisions* (Harvard Business School Press, 1999), written with John S. Hammond and Howard Raiffa, also received the Decision Analysis Society's Best Publication award. It has been translated into 16 languages. Dr. Keeney was awarded the Ramsey Medal for Distinguished Contributions in Decision Analysis by the Decision Analysis Society and is a member of the National Academy of Engineering.

Edward R. Kielty is president of the Hall Chemical Company. He has a B.S. from Long Island University and an M.A. from New York University. Mr. Kielty has spent almost 35 years in the metals industry, starting with African Metals Corporation in 1972 and spending the next 22 years involved in the UM / Sogem Group. In 1992, he was named president of the joint venture company between Gecamines and Sogem, African Metals Corporation. From 1994 through 1998, Mr. Kielty worked at the Hall Chemical Company, where he spent the most of his tenure as the vice president of operations. In 1999, he became a consultant for Anglovaal Mining and was involved in the emerging cobalt project in Zambia at Chambishi Metals PLC. In January 2000, Mr. Kielty became the vice president for marketing and sales at Chambishi Metals PLC. His past and present memberships include the American Society for Metals, the American Powder Metal Institute (past director), the American Institute of Chemical Engineers, the Cobalt Development Institute (past director and member of the statistics committee), the Refractory Metals Association (past president and director), and the U.S. National Defense Stockpile Advisory Committee (chair of the sales and methodology sector).

J. Patrick Looney is the assistant laboratory director for policy and strategic planning at Brookhaven National Laboratory, where he oversees the lab business plan, which determines the direction of its scientific programs, and oversees the Directed Research and Development Program, a competitive program for Brookhaven scientists in which the laboratory awards funding for highly innovative and exploratory research that fits into the mission of the laboratory. Dr. Looney is also responsible for the laboratory's technology transfer functions, including collaborations with industry and work for others and for increasing funding from sources other than DOE. After earning a B.S. in physics from the University of Delaware, Dr. Looney went on to Pennsylvania State University, where he earned an M.S. and a Ph.D. in physics. From 1987 to 2002, Dr. Looney held several research positions at the National Institute of Standards and Technology (NIST), eventually becoming a program analyst responsible for developing policy and program plans for NIST research. In March 2002, Dr. Looney became the assistant director of physical sciences and engineering in the White House Office of Science and Technology Policy, where he worked closely with other White House offices, including the Office of Management and Budget, to coordinate policy development and set budget priorities. Dr. Looney is a fellow of AVS, the American Science and Technology Society.

Graham R. Mitchell is a professor of practice and director of the program in entrepreneurship at Lehigh University, where he is responsible for developing and teaching the university's minor program in entrepreneurship. He received B.Sc. and Ph.D. degrees in electrical engineering from the University of Westminster, London. From 1998 to 2003 Dr. Mitchell was the Bladstrom visiting professor (entrepreneurship) at the Wharton School of the University of Pennsylvania and director of the Wharton program in technological innovation. Between 1993 and 1997 he was appointed as U.S. assistant secretary of commerce for technology policy, where his responsibilities included the development and implementation of policies to increase the role of technology in enhancing the competitiveness and economic growth of the United States. From 1980 to 1993, he was the director of planning and forecasting for GTE (now Verizon), where he developed and operated corporate technology planning systems covering GTE's main businesses in telecommunications, lighting, and materials. From 1968 to 1980 he worked at

General Electric as manager of research, engineering, and business development in operations and with the Corporate Research and Development Center. He is an author of or collaborator on 50 papers and studies in technology, business management, and policy and holds seven U.S. patents. Major honors include the Industrial Research Institute's Maurice Holland award and an award from the International Association for the Management of Technology.

Peter C. Mory completed a B.A. and an M.S. in geology at Case Western Reserve University, following his decorated service in the U.S. Army, including service in Vietnam. In 1973, Mr. Mory joined the U.S. Bureau of Mines (BM), where he conducted fieldwork, evaluated mineral resources, and prepared reports for over 30 forest service areas in the United States. These areas were highly varied in geology and contained energy resources (coal) and metallic and nonmetallic minerals. At that time, Mr. Mory authored or coauthored 20 mineral resource publications of the U.S. Geological Survey. In 1983 he joined the BM Division of Mineral Land Assessment office in Washington, D.C. He served as bureau manager for all mineral resource studies of the U.S. Forest Service and Bureau of Indian Affairs lands. He coordinated the activities of over 90 mineral professionals at three field centers with a budget of over $12 million and developed technical knowledge and in-depth experience of minerals and materials, economics, engineering, geology, industry, and supply and demand for a wide range of metallic and nonmetallic materials and energy resources. In 1992 he became a senior industrial specialist as well as serving as deputy to the chief staff officer at the U.S. Bureau of Mines. At this time he served as emergency preparedness coordinator on the Bureau director's senior advisory staff. His responsibilities there included policy in the domestic and foreign commodities industry, materials, facilities, production processes, and supply and imports of all strategic and critical materials in the Defense National Stockpile. He coordinated and was responsible for the accuracy of all commodities data and information going to the Market Impact Committee and the DNS and was responsible for emergency preparedness planning and actions relating to bureau commodity supply and demand activities (a classified position). Mr. Mory participated as a strategic mineral/materials expert for the Department of the Interior in the annual global war games at the Naval War College at Newport, Rhode Island. When the BM closed in 1996, Mr. Mory joined the Defense National Stockpile Center as a senior industrial specialist and rose to become director of the stockpile's Directorate of Market Research and Planning. There he was responsible for all mineral data and information from the Market Impact Committee members (U.S. Geological Survey and Department of Commerce) to the stockpile. He supervised the development of the Annual Materials Plan detailing the sales level for all materials in the stockpile, which was annually submitted to Congress, and directed research into domestic and international marketing factors such as changes in supply/demand, production, consumption, imports/exports, prices, and stock levels and their impact on markets for stockpile materials.

David C. Mowery is William A. and Betty H. Hasler Professor of New Enterprise Development at the Walter A. Haas School of Business at the University of California, Berkeley, and a research associate of the National Bureau of Economic Research. He received his undergraduate and Ph.D. degrees in economics from Stanford University and was a postdoctoral fellow at the Harvard Business School. Dr. Mowery taught at Carnegie Mellon University, served as the staff officer for the Panel on Technology and Employment of the National Academy of Sciences, and served in the Office of the U.S. Trade Representative as part of the International Affairs Fellowship program of the Council on Foreign Relations. He has been a member of a number of National Research Council committees, including those on the Competitive Status of the U.S. Civil Aviation Industry, on the Causes and Consequences of the Internationalization of U.S. Manufacturing, on the Federal Role in Civilian Technology Development, on U.S. Strategies for the Children's Vaccine Initiative, on Applications of Biotechnology to Contraceptive Research and Development, and on New Approaches to Breast Cancer Detection and Diagnosis. He is currently vice chair of the Committee on Competitiveness and Workforce Needs of United States Industry and he was recently a member of the NRC's National Material Advisory Board's review of the nanotechnology initiative. He was principal editor of the report *U.S. Industry in 2000: Studies in Competitive Performance* (1999), a compilation of STEP studies. His research deals with the economics of technological innovation and with the effects of public policies on innovation; he has testified before congressional committees and served as an adviser for the Organisation for Economic Cooperation and Development, federal agencies, private companies, and industrial firms. Dr. Mowery has published numerous academic papers and has written or edited a number of books, including *"Ivory Tower" and Industrial Innovation: University-Industry Technology Transfer Before and After the Bayh-Dole Act*, *Paths of Innovation: Technological Change in 20th-Century America*, and *The International Computer Software Industry: A Comparative Study of Industry Evolution and Structure*. His academic awards include the Raymond Vernon Prize from the Association for Public Policy Analysis and Management, the Economic History Association's Fritz Redlich Prize, the Business History Review's Newcomen Prize, and the Cheit Outstanding Teaching Award.

Daniel B. Mueller is an associate research scientist in industrial ecology at Yale University, where his research is focused on modeling and scenario building for a wide variety of metals and biomass, as well as characterizing the cycles of different metals throughout their life cycles, in all significant world countries and regions. Dr. Mueller works in close collaboration with various governmental and nongovernmental organizations, which in the case of the United States include the U.S. Geological Survey, the Census Bureau, the Bureau of Economic Analysis, the Environmental Protection Agency, and the United Nations' Statistics Division (international trade). He also works with a variety of industries and industry organizations, such as the Raw Materials Group, the International Iron and Steel Institute, the International Stainless Steel Forum, the Nickel Institute, the Chromium Development Association, the International Molybdenum Association, the Copper Development Association, the International Lead and Zinc Study Group, the International Aluminum Institute, and the International Platinum Association, Earlier, Dr. Mueller was a postdoctoral fellow at Delft University of Technology and a doctoral student at the Swiss Federal Institute of Technology. Dr. Mueller also served as a scientific collaborator at the Swiss Federal Institute for Environmental Science and Technology. He received an M.S. in rural engineering and a Ph.D. in technical sciences from the Swiss Federal Institute for Technology in Zurich. He is a member of the International Society for Industrial Ecology and the International Society for Ecological Economics and serves as a consultant for Organe Consultatif sur les Changements Climatiques (OcCC), in Bern, for its program on the secondary benefits of greenhouse gas reduction measures, and as a reviewer for the journal *Schweizerische Zeitschrift für Forstwesen*, the *Journal for Industrial Ecology*, *Systems Research and Behavioral Sciences*, *Ecological Economics*, and *Waste Management and Research.*

Madan M. Singh is the director of the Department of Mines and Mineral Resources, state of Arizona. He has a Ph.D. in mining engineering and is a registered professional engineer in Arizona. His research interests and areas of expertise encompass aspects of mining, geotechnical engineering, tunneling, subsidence, environmental studies, and other related fields. In 1975, Dr. Singh founded Engineers International and developed it from a one-man operation to a company with a staff of over 50. He has authored over 100 technical papers in addition to serving as associate editor and chapter author on mine subsidence in the SME *Mining Engineering Handbook* and the *Mining Environmental Handbook*. He has chaired several symposia and lectured extensively. Dr. Singh has been involved with a variety of professional organizations, including as national director of the American Consulting Engineers Council, president of the Consulting Engineers Council of Illinois, member of the board of directors of the Society for Mining, Metallurgy, and Exploration, Inc. (SME), chair of the SME Coal Division, and chair of the American Society for Testing and Materials subcommittee on rock strength. In 1996, Dr. Singh was named a Centennial Fellow by the College of Earth and Mineral Sciences at Penn State and was honored with the Robert Stefanko Distinguished Achievement Award by the Department of Energy and Geoenvironmental Engineering in 1999. He won the Howard N. Eavenson Award of SME in 2000 and was selected as a Distinguished

Member in 2004. Dr. Singh has served on two NRC committees related to coal and on the U.S. National Committee for Rock Mechanics and the U.S. National Committee on Tunneling Technology.

Kathleen Walsh is assistant professor of national security affairs in the National Security Decision Making Department of the Naval War College where she teaches a master's-level seminar on how to analyze the U.S. policy-making process (PMP) to U.S. Navy personnel and select officers from other military services, domestic and international. She is also involved in curriculum development for the PMP course and conducts ongoing research and writing on issues where she has established expertise, including U.S.-China relations, China's evolving science and technology strategy, issues of technology transfer and proliferation of arms and weapons of mass destruction, as well as U.S. and multilateral export control policy. She has also worked as a consultant with the Henry L. Stimson Center on Post-Conflict Border Security and Trade Controls. Prior to joining the faculty of the Naval War College, she was an independent consultant to the U.S. government, research enterprises, and Washington-area think tanks. From 2000 to 2004, Ms. Walsh was senior associate at the Henry L. Stimson Center, where her research focused on Asia, primarily China, and related issues of technology transfer, proliferation, and security. From 1997 to 2000, she was senior associate at DFI International, a private defense consulting firm. Ms. Walsh's extensive experience in Washington, D.C., includes work for several departments in the executive branch, Congress, and both public- and private-sector research institutions and think tanks. She is the author of several publications and numerous articles, reports, briefings, and congressional testimonies. She holds an M.A. in international security policy from Columbia University and a B.A. in international affairs from George Washington University.

Jim Williams is professor of materials science and engineering and Honda Chair at the Ohio State University (OSU). From 2001 until 2004 he was dean of engineering and Honda Chair, also at OSU. Until 1999 he was general manager of the Materials and Process Engineering Department at GE Aircraft Engines. He is a member of the National Academy of Engineering, a fellow of TMS/AIME, and a fellow of ASM International. He is the recipient of the 1992 ASM Gold Medal, the 1993 TMS/AIME Leadership Award, the 2002 TMS/AIME Application to Practice Award, and the International Titanium Association's 2003 Achievement Award and was inducted into the GE Aircraft Engines Propulsion Hall of Fame in 2003. He was chairman of NRC's National Materials Advisory Board from 1989 to 1995. He was a member of the Oversight Committee of the NRC's Division of Engineering and Physical Sciences from 2000 to 2005. He was a member of the MST Division Review Committee from 1993 to 1999 and the ESA Division Review Committee at Los Alamos National Laboratory from 2000 to 2006. He served on the U.S. Air

Force Scientific Advisory Board from 1994 to 2000. Prior to joining GE in 1988, he spent 13 years at Carnegie Mellon University as professor, president of the Mellon Institute, and dean of engineering. Before joining Carnegie Mellon he held research and engineering positions with Rockwell and Boeing. He has consulted extensively for government and industry. He has published more than 200 papers based on his research. His professional interests include structure-property relations of high-strength materials, the performance of materials in extreme environments (temperature, stress and strain rate), materials processing, and technology policy, particularly as it pertains to materials and the management of high technology organizations. In much of his work he specialized in titanium alloys. In 2003 he and G. Lütjering wrote the book *Titanium*, published by Springer-Verlag, which released a second edition in the spring of 2007. Dr. Williams received B.S., M.S., and Ph.D. degrees in metallurgical engineering from the University of Washington.

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Acronyms

AMP	annual materials plan
BCMA	beryllium-copper machined alloy
BEM	Brush Engineered Materials
BOM	Bureau of Mines
BRIC	Brazil, Russia, India, China
BUR	bottom-up review
BWI	Brush Wellman, Inc.
CBO	Congressional Budget Office
CDC	Centers for Disease Control and Prevention
CFIUS	Committee on Foreign Investment in the United States
CIA	Central Intelligence Agency
CONUS	continental United States
CRAF	Civilian Reserve Air Fleet
DARPA	Defense Advanced Research Projects Agency
DHS	Department of Homeland Security
DLA	Defense Logistics Agency
DNSC	Defense National Stockpile Center
DoD	Department of Defense
DOE	Department of Energy
DPAS	Defense Priorities and Allocation System

DSB	Defense Science Board
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FORCEMOB	Force Mobilization (model)
FY	fiscal year
GAO	Government Accountability Office (General Accounting Office before July 2004)
GDP	gross domestic product
GOCO	government-owned, contractor-operated
GOGO	government-owned, government-operated
GSA	General Services Administration
GWOT	Global War on Terror
HASC	House Armed Services Committee
HPP	hot pressed powder
IDA	Institute for Defense Analyses
IED	improvised explosive device
IG	Inspector General
ILIAD	Interindustry, Large-scale, Integrated, And Dynamic (model)
IMF	International Monetary Fund
JOGMEC	Japan Oil, Gas and Metals National Corporation
LIFT	Long-term, Interindustry Forecasting Tool (model)
MCO	major conflict operations
MCR	materials consumption ratio
MCTL	Military Critical Technologies List
MDA	Missile Defense Agency
MEMS	microelectromechanical system
METI	Ministry of Economy, Trade, and Industry (Japan)
MIC	Market Impact Committee
MRAP	mine-resistant ambush protection
MRC	major regional conflict
MSE	materials science and engineering
MTW	major theater war

NAFTA	North American Free Trade Agreement
NATO	North Atlantic Treaty Organization
NCMP	National Commission on Materials Policy
NDS	National Defense Stockpile
NDSt	National Defense Strategy
NMS	National Military Strategy
NRC	National Research Council
OSD	Office of the Secretary of Defense
QDR	Quadrennial Defense Review
REE	rare earth element
R&D	research and development
RMA	revolution in military affairs
SCADA	supervisory control and data acquisition
SCM	strategic and critical material
SMPD	Strategic Materials Protection Board
SNS	Strategic National Stockpile
SPR	Strategic Petroleum Reserve
USGS	U.S. Geological Survey
VMI	vendor-managed inventory
WMD	weapon of mass destruction